EXTRACT TM 11-678

CHAPTER 1
SOUND

1. Sound and Telephony

Until the invention of the telephone, the distance over which the human voice could be used for communication was limited by the lung power of the speaker and by the ear sensitivity of the hearer. This limited distance could be extended slightly by a megaphone, a large horn which concentrates the power of the human voice in a given direction. Megaphones increased intelligibility where it was necessary to shout in order to be heard, as from ship to ship at small distances. It is interesting to note that the words *mega-phone* and *tele-phone* both are made up in part of the English equivalent of the Greek word *phone*, which means sound. The word megaphone means simply a big sound, and the word telephone means sound at-a-distance, or far sound.

a. The telephone, as its name implies, solves the problem of distance limitation on sound transfer from point to point. Of course, the first telephone was crude and its usefulness was limited. Many stages of development were necessary to bring it to its present efficiency and flexibility. But development was rapid, and today, spurred by enormous demands, the service provided by telephone reaches almost everywhere; a business executive or a commanding general by picking up a telephone can communicate not only with an associate in the next room or in his immediate vicinity but, almost at once, with someone on the other side of the earth.

b. The sound of the voice of the speaker actually is not transmitted over long distances, but a sound *like* the voice of the speaker is generated at the distant point by means of electrical power. The small voice power of the speaker is transformed into electrical power, which may be amplified at will, and then this electrical power is transmitted over wires to any given point, where it is changed into sounds that resemble the voice of the speaker. Radio communication, which was a later solution of the same problem, transmits electrical energy without wires, and hence in its early stages of development was called *wireless* to distinguish it from the telephone and the telegraph. The *radio telephone*, a more recent development, uses both the wire and the wireless forms of transmission. For instance, the transatlantic telephone uses wire wherever the local telephone system is capable of handling the message, and wireless is used for the long hop over the ocean from the terminals in New Jersey and on Long Island to the terminals of Europe.

c. Any telephone system begins and ends with sound, and therefore this chapter will concern itself with the origin and characteristics of sound waves and will serve also as an introduction to the elements and operational techniques of the basic telephone system with which the following chapters are concerned. The coils, capacitors, transformers, switches, switchboards, transmission lines, power sources (including both wet and dry-cell batteries), and the transmitters and receivers in the telephone instrument itself are described in detail. A major portion of this manual is devoted to an analysis of local-battery and common-battery circuits, either of which are basic to any telephone system, including Army field telephones and the more intricate circuits of dial systems.

2. Nature of Sound

Sound is the sensation caused in the nervous system by vibration of the delicate membranes of the ear. An analysis of sound as sensation is outside the province of this text, but the cause of sound by physical vibrations can be analyzed and measured with accuracy. As illustrated in figure 1, the sensation of sound results from the rapid vibrations of a rigid or semirigid body such as a hacksaw blade, a tuning fork, a drum head, or a bell. If a pencil is held lightly against the vibrating body, the physical motion often can be felt by the hand; but without the pencil as a medium for the transfer of energy, the vibrations cannot be felt by the hand at even a small distance from the source. At the same time, however, these vibrations are recognized by the ear as

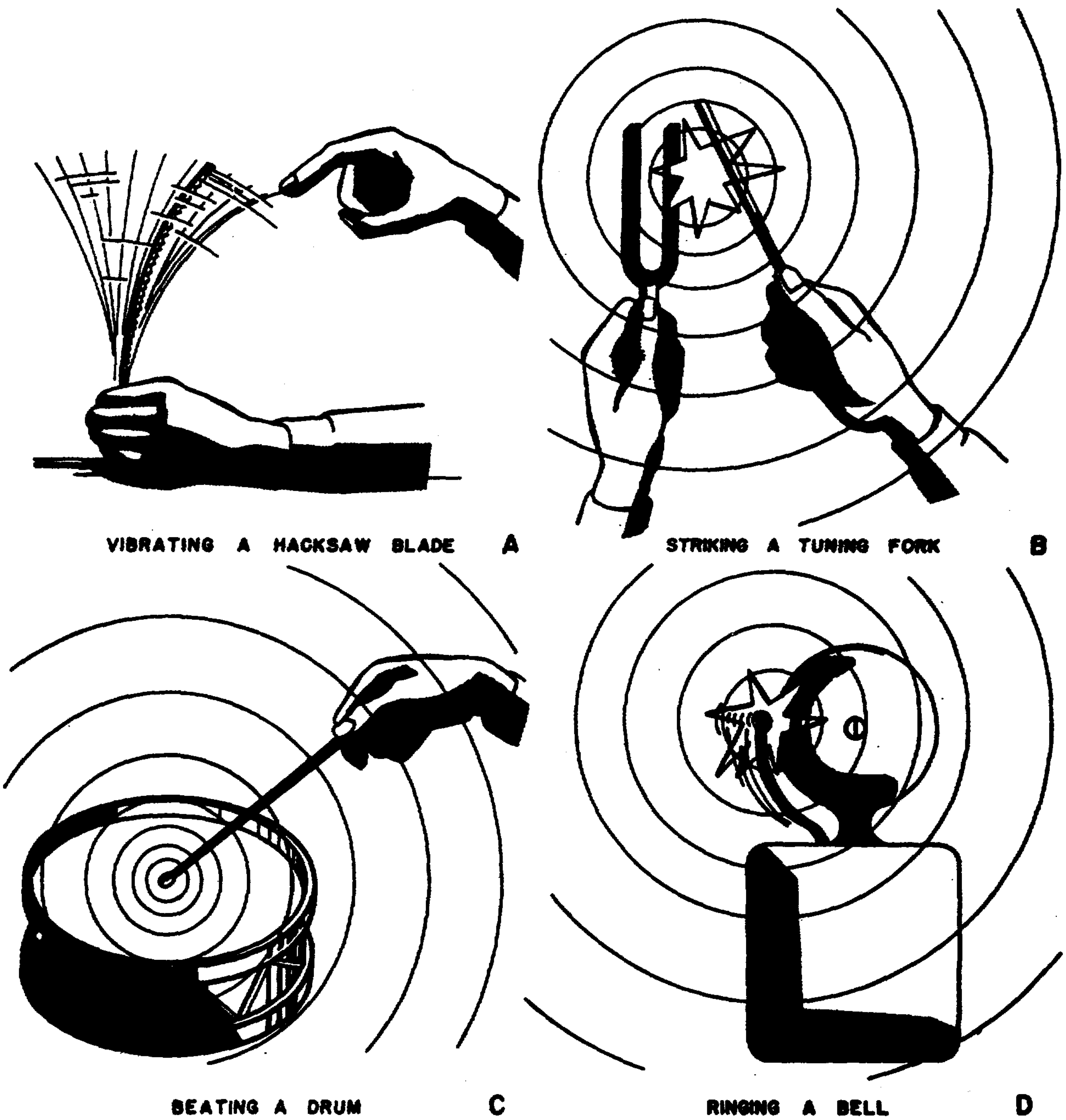

Figure 1. Generation of sounds.

sound. The physical medium between the source of vibrations and the ear is the surrounding body of air, which at atmospheric pressure is sufficiently dense to be set in motion by the vibrating body and to convey the vibrations to the delicate and sensitive membranes of the ear.

3. Transmission of Sound

a. An important fact to note here is that sound, unlike light and electromagnetic (radio) energy, requires a conducting medium. This fact is illustrated by figure 2, which shows an electric bell

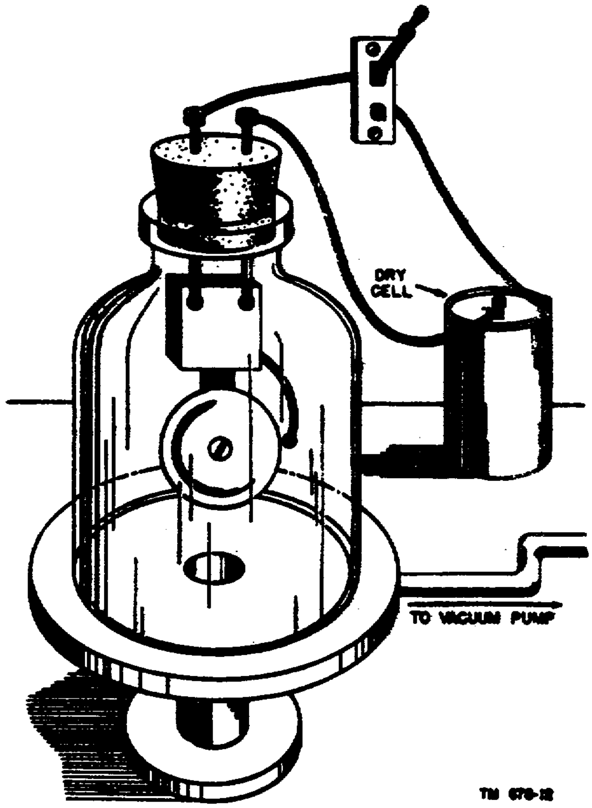

Figure 2. Bell operating in vacuum.

suspended by its terminal wires from the stopper of a jar which itself rests upon a plate connected to a vacuum pump. A dry cell and a switch are connected to the wires, and the place of exit of the wires is sealed.

(1) When the air is removed from the jar and the bell circuit is closed, no sound is heard, even though the bell is seen to be vibrating.

(2) When air is readmitted slowly, the ringing begins to be heard, and, as more air is admitted, the sound becomes louder.

(3) In the vacuum, sound was not transmitted, whereas in air it was transmitted. Air, therefore, constitutes a medium through which sound can be transmitted.

b. The transmission of sound *always* requires a medium. The transmission of light and electricity does not. Thus, sound cannot be transmitted in a vacuum, but light and electricity can. In the direct transmission of sound, the medium is usually the air intervening between the source and the listener, but other mediums, either solid or liquid, can transmit sound. For instance, a boy lays his ear against a railroad track to detect the presence of an oncoming train which is to far away for its sound to reach him through air; and the American Indian is reputed to have been able to detect far-away footsteps by pressing his ear to the ground. In both cases, the denser medium carried a given amount of sound farther than the sound traveled in air. This principle is used also in underwater detection of ships. Sensitive listening devices attached to the hull of the ship pick up the sound of propeller vibrations carried by the sea from other ships in the vicinity, particularly from submarines.

4. Sound Waves

The motion of the air molecules set up by a body vibrating in air produces *sound waves* which travel outward in all directions from the vibrating source. The manner in which sound waves are produced can be understood by considering a vibrating strip of metal, such as the hacksaw blade illustrated in figure 3.

a. A hacksaw blade is fastened to a table in a vertical position, as in A, and, with a finger, is caused to vibrate rapidly back and forth. As it makes its initial trip to the right, two events of opposite nature occur, as shown in B. One, the blade increases the pressure existing in the group of air particles adjacent on its right, causing a local *condensation*, or bunching-up, of the particles on that side. Two, the blade decreases the pressure existing in the group of air particles adjacent on its left, causing a local *rarefaction*, or dispersion of the particles on that side. Condensation and rarefaction occur at the same time, and are caused by the single motion of the blade to the right.

b. Free to vibrate by itself, the blade starts to move back to its vertical position of rest, as in C; but *motion* has been imparted to the particles on each side and their subsequent behavior is affected. The bunched-up group on the right has been given a velocity outward, and pushes against the layer of particles still farther to the right. Great numbers of minute collisions occur, and gradually but very rapidly the striking particles give up to their neighbors their own motion and bunched-up arrangement. This accounts for the new position of the regions of condensation and rarefaction. This progress outward continues, the wave of sound energy moving outward, and the individual

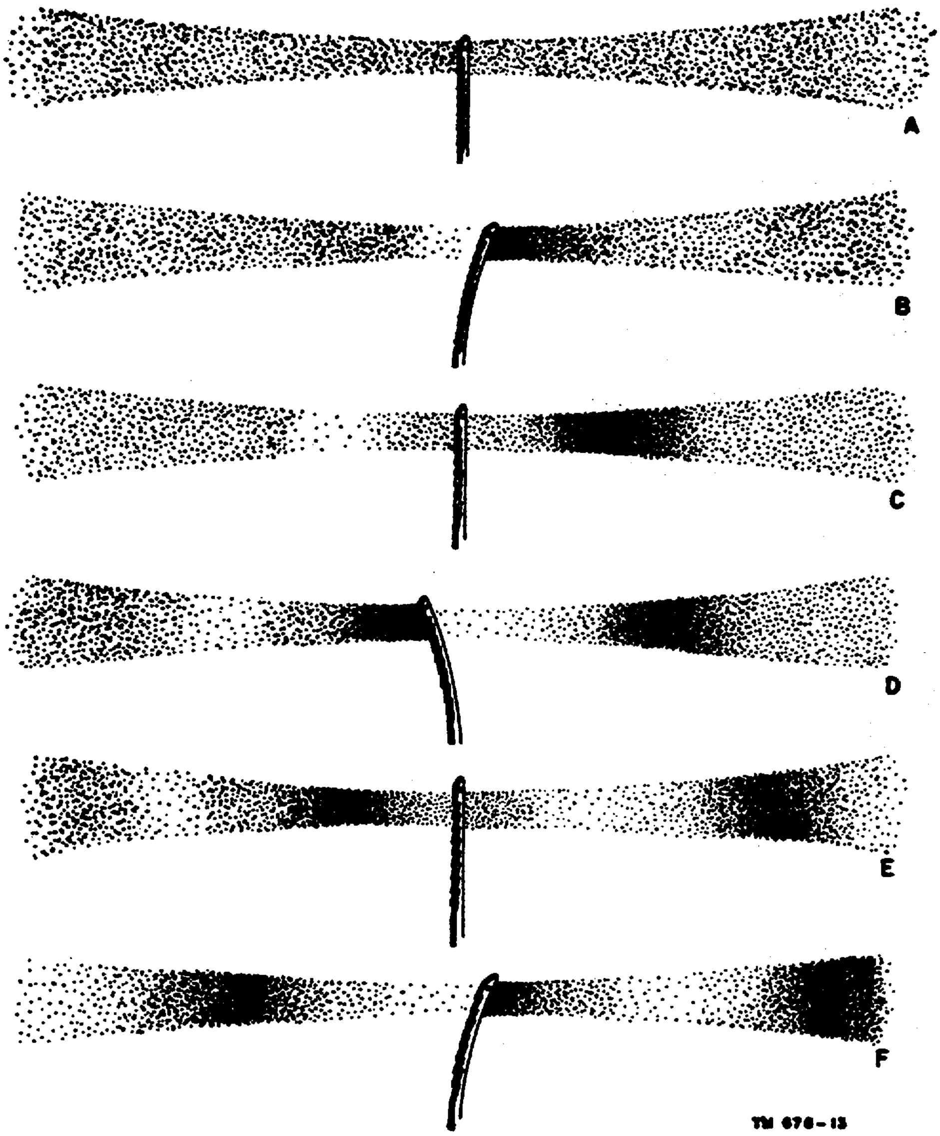

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Figure 3. Sound wave produced by vibrating blade.

air particles that transmit the motion remaining behind.

c. As the blade returns left toward the vertical and the condensation travels outward to the right, an increasing gap occurs between them, as shown in C. This region becomes one of lessening pressure, because the nearby air particles tend to rush in and fill the gap to normal density. By the time the blade reaches the vertical, the pressure immediately to its right has decreased to about normal, and normal pressure has been restored just to its left.

d. The blade at this point has a good deal of velocity, and continues to the left as in D. It now has caused a condensation on its left and a rarefaction on its right. The initial condensation on the right, meanwhile, has progressed still farther from the blade, and the initial rarefaction still farther to the left.

e. In this way, at each advance of the blade on either side, a crest of condensation is sent traveling outward; and at each retreat of the blade an intervening trough of rarefaction is established. The energy of each wave, crest to crest, was given to it by transfer of the energy of motion of the blade. This energy, now called a *sound wave*, continues outward. The air particles which transmit the energy do not go along with it; each collides with its outside neighbors, imparts its energy, and returns to a point close to its original position.

Thus, with the blade again vertical, normal pressure is restored on both sides of the blade, as in E. By this time, both condensations and rarefactions have moved farther out from the source, and they are followed, in F, by a new wave which has been forming. The process continues, and a train of waves is sent out as long as the vibration continues. A wave such as this, in which the transfer of motion (energy) occurs in the same line as that along which the particles of the medium are oscillating, is called a longitudinal wave.

5. Representation of Sound Waves

a. Sound waves may be represented on a graph by plotting against *distance* the relative compression of the air particles of successive groups along the path of motion, or by plotting against *time* the relative compression of the air particles of successive groups along the path of motion.

(1) In figure 4, a portion of E, figure 3, is redrawn, showing the particles comprising several sound waves. The alternate regions of condensation and rarefaction are moving toward the right, as described in the preceding paragraph. Below this representation is a graph, on which the vertical distances correspond to the relative compression of the air particles along the path of the wave. Note that the highest points of the curve (positive peaks) lie beneath places of maximum condensation, the lowest points of the curve (negative peaks) lie beneath places of maximum rarefaction, and points on the horizontal axis lie beneath places of medium density.

(2) Since the wave is traveling to the right, the ear of the listener experiences variations of pressure identical with those existing along the path of the wave (fig. 4): first, the rarefaction farthest to the right, then the adjacent condensation to the left, and so on. This is because the entire train of waves is moving toward the ear from the left. For this reason, the graph of pressure against time at any point is identical with the graph of pressure against distance at any instant, and horizontal *distances* may represent intervals of time.

(3) The curve represents the sound waves set up by an object vibrating 400 times each second. The time required for each complete vibration is, therefore, 1/400 second, or 2.5 milliseconds.

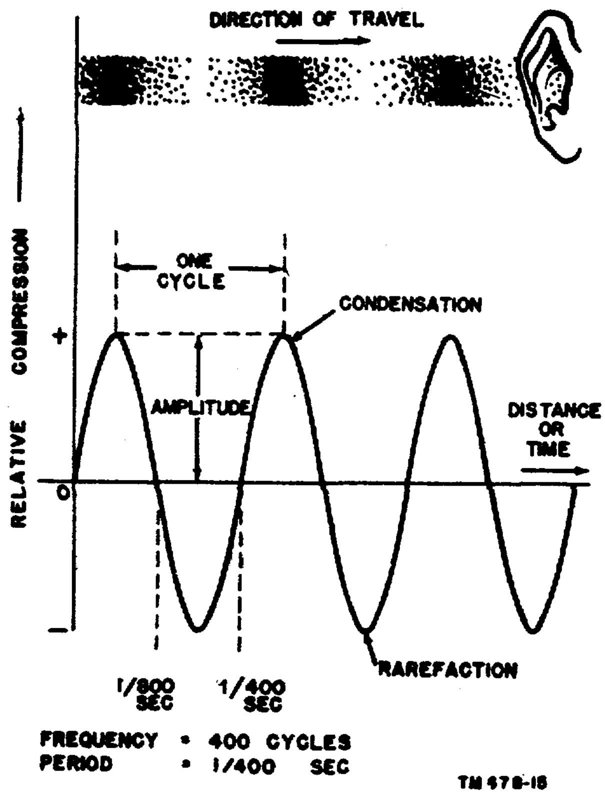

Figure 4. Waveform of simple sound.

b. The number of complete vibrations of the object that occur in 1 second is the same as the number of cycles of the wave that occur in 1 second. This number is called the *frequency* of the wave. A *cycle* is a complete set of pressure values, from one positive peak to the next, anywhere along the path of the wave. The words *per second* usually are omitted, but understood, in referring to frequency, so that the frequency is expressed only in cycles—though sometimes cps (cycles per second) is used. The time required for 1 cycle to occur is called the *period* of the wave. It usually is measured in seconds or milliseconds. The period is the reciprocal of the frequency. For example, the frequency of the waveform illustrated in figure 4 is 400 cycles, but the period is 1/400 second, or 2.5 milliseconds.

c. The maximum value of the wave measured from the zero axis is called the *amplitude* of the wave. The expressed value of the amplitude of a wave depends upon the units used in measuring the relative compression of the particles. The ordinates of the graph may represent dynes per

square centimeter—a unit of pressure—in order that the amplitude of the wave may correspond to the maximum pressure exerted on the particles.

6. Velocity and Wavelength

a. Velocity. Since a definite length of time is required for sound to travel from one point to another, sound waves possess velocity. In air at 0° C., the velocity of sound waves is about 1,090 feet per second. This velocity increases as the temperature rises, so that at 20° C. the velocity of sound is about 1,130 feet per second. In denser mediums the velocity of sound is greater. In water, for example, sound waves travel at 4,700 feet per second. In solids, the velocity of sound waves is usually many times the velocity in air. Light waves and electromagnetic waves, by comparison, travel at the extremely high velocity of 186,000 *miles* per second—more than 700,000 times as fast as sound. This huge difference in velocity explains why the lightning flash (light) is seen several seconds before the far-off thunder (sound) is heard. Since light travels practically instantaneously for short distances, the distance between a storm center and an observer can be calculated readily by counting the number of seconds between the flash of lightning and the peal of thunder, and then multiplying this figure by the velocity of sound. For example, if there is an interval of 5 seconds between flash and peal, and if the velocity of sound is taken as 1,100 feet per second, the center of the storm is 5 times 1,100, or 5,500 feet from the observer. At ordinary speaking distances, the time required for sound waves to travel from one person to another is too short to be of any importance. It can prove disturbing, however, when the distance separating the source and the observer is relatively great, as it frequently is in a large public hall or stadium.

b. Wavelength. A sound wave, like an electromagnetic or light wave, may be characterized or identified by its *wavelength*. The wavelength is the actual distance between successive condensations or successive rarefactions along the path of the sound. Thus, in figure 4, the distance covered by the portion of the wave designated as *one cycle* is the wavelength. The wavelength of a sound wave can be calculated by using the relationship:

$$\text{wavelength} = \frac{\text{velocity of the sound.}}{\text{frequency of the sound}}$$

A sound wave with a frequency of 1,000 cycles, traveling at a velocity of 1,130 feet per second, has a wavelength of 1,130/1,000 or 1.13 feet. At the same velocity, the wavelength of the 400-cycle sound represented in figure 4 is 2.82 feet. As the frequency increases, the wavelength decreases; as frequency decreases, wavelength increases if the medium remains the same. Audible sounds, which range approximately from 20 to 20,000 cycles, have wavelengths ranging from 55 feet to ⅔ of an inch, if the medium is air. Electromagnetic waves, in air, of the same frequencies as these have wavelengths ranging from about 9,300 miles to 9.3 miles. These latter wavelengths are much longer because their velocity is much greater. Light waves, even though their velocity is the same as electromagnetic waves, have such extremely high frequencies that their wavelengths are less than 1/1,000,000 of an inch.

7. Complex Sounds

a. Harmonics. Most sound sources in telephony do not produce sounds of the simple form represented by the sine wave of figure 4. Those usually encountered are called *complex sounds*. Complex sounds consist of two or more simple sounds, each having its own frequency and amplitude. A graph of such a sound would not be a simple sine wave. Any complex sound may be separated into its component simple sounds and their frequencies, however, as is shown by the graph of a musical tone in figure 5. The lowest frequency contained in such a sound is called the *fundamental frequency*, often simply called the *fundamental*. All others are *harmonic frequencies*, also called *overtones*. Harmonic frequencies are whole-number multiples of the fundamental. The fifth harmonic, for example, has a frequency five times that of the fundamental. For a complex sound having a fundamental of 400 cycles, the fourth harmonic is 1,600 cycles, the sixth harmonic is 2,400 cycles, and so on. It should be noted that, by this definition, the first harmonic is identical with the fundamental frequency.

b. Voice Sounds. All voice sounds are complex sounds. The existence of the different sets of harmonics contained in voice sounds helps us to distinguish the voices of different people, and does much to make the voice expressive of such feelings as gladness, sorrow, and anger. The harmonics of the voice are of considerable importance in telephony, for any part of the telephone system which suppresses or distorts them makes the trans-

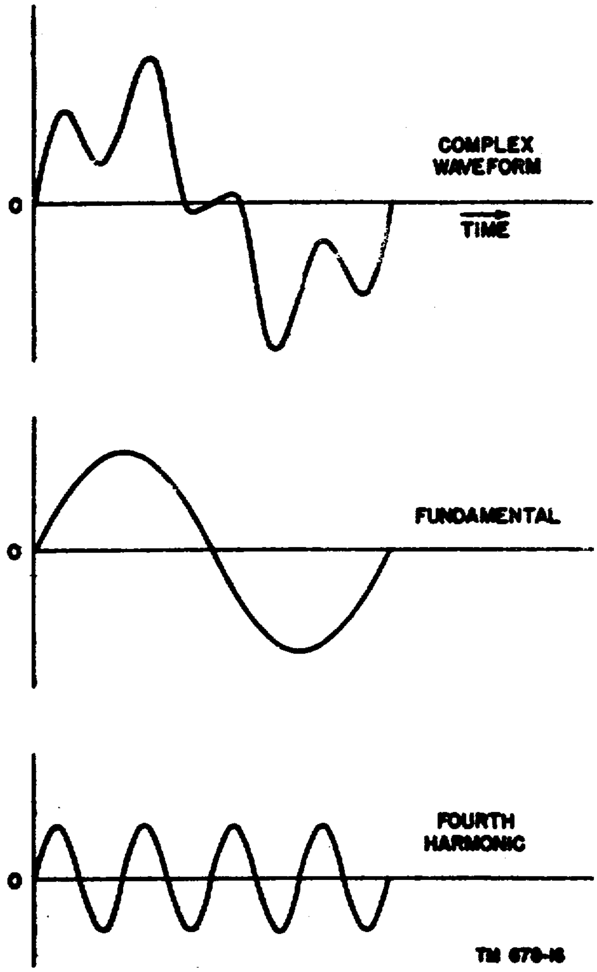

Figure 5. Analysis of complex waveform.

mitting voice less intelligible. Basic voice sounds occur in the variations and combinations of the five vowels (a, e, i, o, u) and the consonants. The basic voice sounds of different languages vary somewhat. Waveforms of two vowel sounds are shown in A, figure 6.

c. Musical Sounds. Just as the different harmonics contained in the sound waves produced by voice enable the listener to distinguish one voice from another, so the different harmonics contained in the sound waves produced by different musical instruments playing the same note enable him to distinguish one instrument from another. Middle C struck on a piano is distinguished easily from the same note played on a violin. It is largely the richness in harmonics of a musical sound that makes it pleasing to the ear. Chords are pleasing because all the harmonics of the individual notes blend. The waveform of a musical note is illustrated in B.

d. Noise. *Noise* can be distinguished from either speech or music by the irregularity of its waveform. An examination of the waveforms illustrated shows that the waves of the sounds of speech and music are similar in that they have regularity of variation. In both, portions of the wave recur at regular intervals; but this is not true of the waveform representing noise, in C. Noise results in a relatively unpleasing sensation. It rarely has any perceptible rhythm, and its frequency content is difficult to determine. The random or background noise in a room often has a disturbing effect on a listener, and actually may render a conversation unintelligible. Distorted speech or music also may be mere noise when it becomes unintelligible.

8. Characteristics of Sound

Every sound made by musical instruments and the human voice has three identifying properties or characteristics: pitch, loudness, and quality.

a. Pitch of Sound. *Pitch* is the relative highness in frequency of a sound, and its value depends on the frequency of the wave, which in turn de-

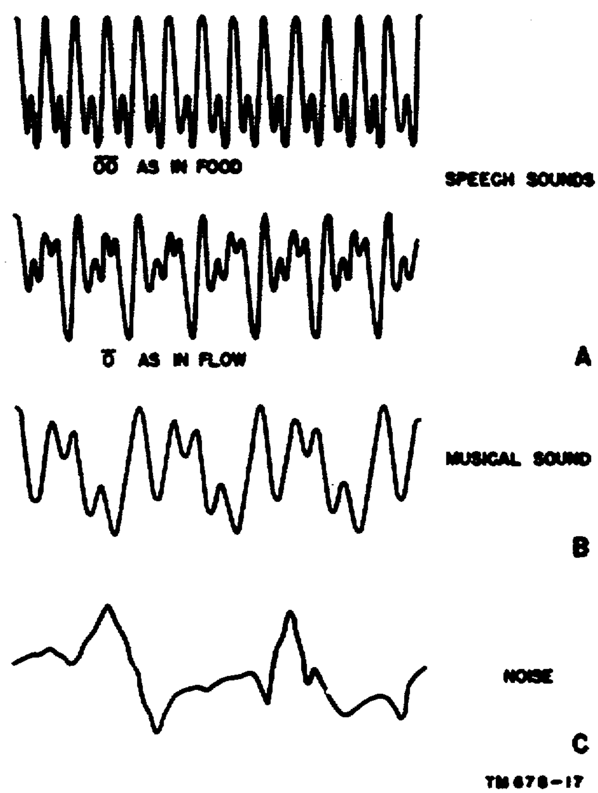

Figure 6. Waveforms of speech, music, and noise.

pends on the number of vibrations or cycles (per second) produced by the vibrating body. The voice of a soprano is higher in pitch than the voice of a basso, the yowling of a tomcat is higher in pitch than the roaring of a lion, the sound made by a peanut vendor's whistle is higher in pitch than that of a fog-horn. The pitch of a complex wave is determined by the fundamental frequency: the higher the frequency, the higher the pitch. The lowest musical sound that the human ear can detect has a frequency of about 20 cycles; the highest has a frequency of about 20,000 cycles. In order for the sound produced by the vibrating hacksaw blade to be audible, it must vibrate at a rate between 20 and 20,000 vibrations per second. Since sounds having frequencies appreciably above 20,000 cycles are beyond the audible range, they are called *ultrasonics*. The musical standard of pitch is the note middle C, which has a frequency of 256 vibrations per second.

b. Loudness of Sound. The *loudness* or intensity of a sound refers to a *sensation* created in the human ear. Since estimates of loudness made by people vary greatly, a standard instrument must be used to measure loudness accurately. So measured, the loudness of a sound is found to depend on two factors: the amplitude of vibration of the source, which determines the amplitude of the sound wave produced, and the distance between the source and the measuring instrument or ear. With constant distance and a uniform medium, the loudness of a sound depends only on the amplitude of vibration of the source. The harder the prong of a tuning fork is struck, the harder a drum is beaten, the larger is the amplitude of vibration, and the louder the sound produced, since the amplitude of vibration depends on the initial energy imparted. Sound usually is measured in watts per square centimeter. Figure 7 and table 1 illustrate relative intensity of some commonly heard sounds.

c. Quality of Sound. The third characteristic of sound, quality, sometimes called *timbre*, is vital to the *recognition* of sounds and voices. The note A played on a violin has a special quality (peculiarity) which the same note played on a flute does not have: A note from a violin is recognized as coming from a violin; a note from a flute is recognized as coming from a flute. A sleeping mother wakes at the cry of her own child but not at the cry of the one next door, because even though asleep she recognizes the particular quality of the voice of her own child. Much of this recognition

Table I. Relative Intensity

Sound	(Watts/cm²)	Description
Artillery, thunder, nearby riveter, boiler factory.	10^{-5}	Deafening.
Loud street noise, noisy factory, unmuffled truck, police whistle.	10^{-7}	Very loud.
Noisy office, average street noise, average radio, average factory.	10^{-9}	Loud.
Noisy home, average office, average conversation, quiet radio.	10^{-11}	Moderate.
Quiet home, private office, average auditorium, quiet conversation.	10^{-13}	Faint.
Rustle of leaves, whisper, soundproof room.	10^{-15}	Very faint.

Note. $10^{-5} = 1 \times 10^{-5} = .00001$
$10^{-7} = 1 \times 10^{-7} = .0000001$

of quality depends on the particular combination of harmonics contained in the sound, as has been explained; the rest depends on the frequencies and intensities of the harmonics of the sound, relative to the fundamental. A particularly pleasing voice (for other than sentimental reasons) is generally a voice rich in overtones. Note that the word *quality* has two meanings, a lesser one associated with pleasantness and a principal one associated with identity. To any individual, the quality of a particular sound may or may not be pleasant, but the quality helps to identify the object or instrument or person that is its source.

9. Characteristics of Speech

a. Human speech has all the basic characteristics of sound, as previously explained, but it has in addition certain peculiarities of its own. The vocal cords are the vibrating source in the production of most vocal sounds. They are vibrated by the power of the air stream forced between them by the lungs. Vocal cords can be compared to the vibrating strings of a violin, which changes pitch by varying the length of strings of different thicknesses. The range of pitch of the voice is determined similarly, the vocal cords becoming thicker and shorter, or thinner and longer, while speaking. The power furnished by the lungs determines the loudness or volume of the sound produced. Thus, we are aware usually of the greater

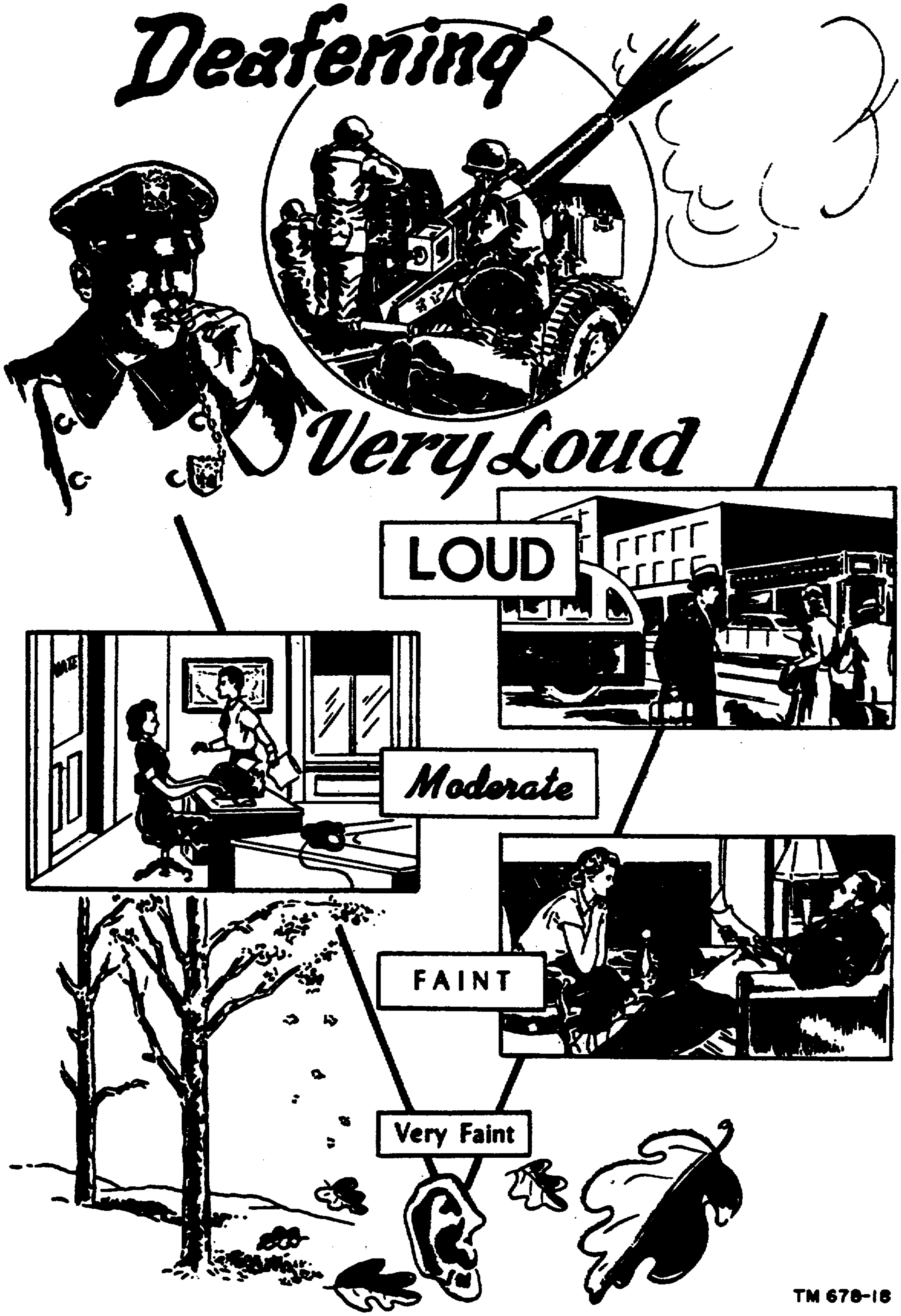

Figure 7. Relative intensity of natural sounds.

effort required to shout than to whisper. This action of the lungs in generating power is like the compressive action required in the playing of an accordion.

b. The throat, mouth, and nasal passages contribute to the quality of the sound produced by the voice. Also, the size and shape of the tongue, the palate, the jaws, and the lips vary the size and shape of the vocal passages and, therefore, determine the number and proportions of the various harmonic frequencies in the resulting sound. Even the upper nasal cavity and the bone structure of the head affect the quality of the voice; they reinforce some of the harmonics and weaken others. The action of these organs can be compared to the action of various wind instruments, differences in size and shape and materials affecting the quality of the musical sounds produced.

10. Inflection

The inflection or modulation which is imparted to the human voice in speaking indicates to a great extent the thought of the speaker and the significance of what he says. *Inflection is the small variation in pitch or loudness which a speaker uses to place emphasis or special meaning on his words.* A crisp *no* and a long-drawn-out *no-o-o* mean different things, even though both sounds essentially are the same. Inflection is also the use of pauses of varying length for imparting meanings. Thus, different inflections are used for commands, questions, or statements of fact, and to express attitudes, feelings, and emotions. Inflection is an important factor in determining the intelligibility of a spoken word or phrase, and therefore persons who use devices or equipment for the transmission of speech—telephones and microphones—must be conscious of their speech habits. They must concentrate on correct inflection and on the shaping of their tones, so that as much as possible of the meaning of their words is transmitted to their listeners. Vowel sounds must be made with the proper amount of mouth opening, and consonants must be formed by the correct placement of the tongue and lips.

11. Frequency Range of Voice Sounds

a. The *frequency range of the voice* is one of the most important factors affecting the design and construction of telephone lines and equipment. Figure 8 illustrates the frequency range of the piano keyboard, together with the ranges of the voices of men and women and those of a number of musical instruments. The sounds of the normal speaking voice contain fundamental frequencies between 100 and 300 cycles. The overtones contained in these sounds extend the range of frequencies to approximately 5,000 cycles. *Voices of different individuals vary in their frequency content.* Men usually have voices with lower fundamental and harmonic frequencies than those of women and children. The range of fundamental frequencies of the singing voice is greater than that of the speaking voice; it varies from about 80 cycles for a deep bass to about 1,200 cycles for a high soprano. The overtones contained in the sounds of the singing voice reach as high as 10,000 cycles. For purposes of comparison, the frequency range of the instruments of a symphony orchestra includes fundamentals of about 16 to

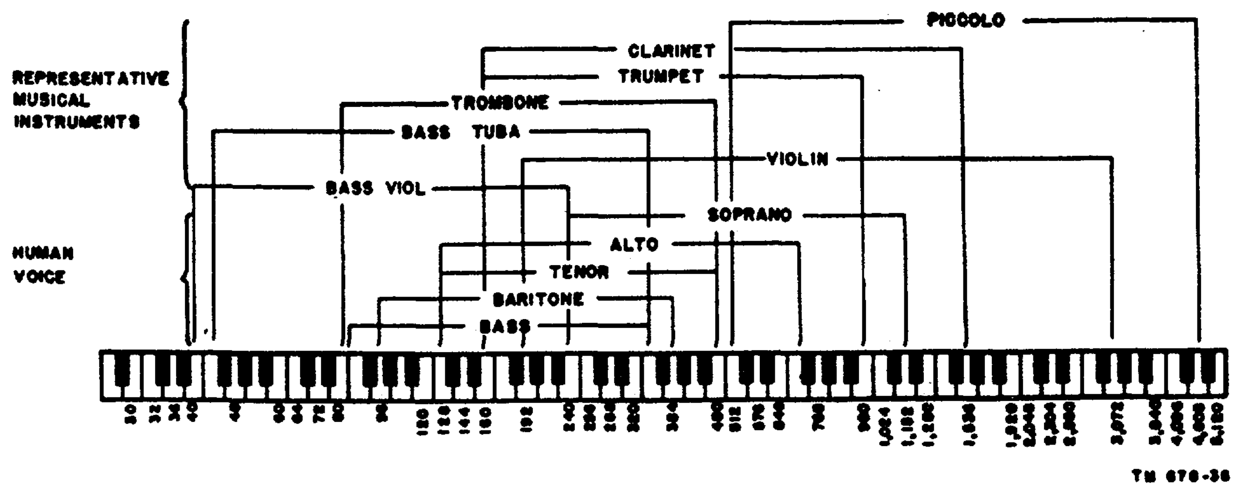

Figure 8. Fundamental frequency ranges of instruments and voices.

4,000 cycles, with overtones ranging to 12,000 cycles or higher.

b. Because of the greater range of frequencies contained in musical sounds—voice and instrument—telephone circuits designed for their transmission must be more complex, and must be constructed to more rigid specifications, to prevent distortion. This increases both the initial cost of the equipment and the expense of maintaining it. For transmission of ordinary conversation, however, it has been found that a sufficiently high degree of intelligibility can be achieved if the frequencies transmitted are limited to those between approximately 200 and 2,700 cycles. This is the range of frequencies with which the various circuits and equipment to be discussed in this manual are concerned.

12. Sound Power

The *power* contained in the sounds of speech depends on the power furnished by the lungs. It varies considerably during an ordinary conversation, with the inflections given to the voice. The average power contained in speech at a normal conversational level is about 1/100,000 watt, or 10 microwatts. By comparison, the average power of speech conducted as loudly as possible is about 1,000 microwatts. Words spoken in as weak a voice as possible, without whispering, have an average power of about 1/10 microwatt; words whispered may have an average power as low as 1/1,000 microwatt. In ordinary speech, the vowels contribute the greatest power, reaching a maximum of about 2,000 microwatts. The power in speech sounds is an important factor in the design and operation of telephone equipment, because the equipment must be able to respond to the differences in power delivered by the voice.

13. Hearing

a. Hearing is the perception of sound by the brain. It involves the response of the ear to sound waves, the transmission of impulses through nerves to the brain, and perception by the brain of the transmitted intelligence. There is a measurable variation among individuals in the ability to hear, since hearing for a given person depends on the loudness and pitch of the sound. An approximate determination of hearing ability in terms of loudness only can be made by measuring the maximum distance at which the ticking of a watch can be heard. A more complete and accurate method involves the use of a device called an audiometer. The audiometer enables an experienced operator to construct a scientific graph of the hearing ability of an individual. This graph then may be compared to what generally is accepted as normal hearing ability. The audiometer consists of a calibrated audio oscillator, the frequency and amplitude of which may be varied, and a telephone receiver for the reproduction of sound waves. The frequency can be varied from 0 cycle to about 25,000 cycles per second, and the amplitude can be adjusted to make the intensity of the sound (loudness) vary through a wide range.

b. In conducting a test with the audiometer, the instrument first is adjusted to any chosen frequency—for example, 1,000 cycles—then, at that frequency, adjusted to an amplitude so low that the sound from the receiver is inaudible. The amplitude then is increased gradually until a point is reached where the sound becomes just perceptible to the ear of the person being tested. This point is called the *threshold of audibility* for that frequency. For any given frequency, it is the lowest intensity at which sound is audible. In the normal ear, the threshold of audibility varies with the frequency of the sound, so that its ability to hear some frequencies is greater than the ability to hear others. In addition to this variation, the threshold of audibility for different frequencies is different for different individuals. For these reasons, a number of frequencies are tested in the measurement of hearing with an audiometer. The lower curve of figure 9 shows how the average, or normal, threshold of audibility varies with sound frequency. The dip in the lower curve indicates that the average ear is most sensitive to frequencies in the vicinity of 2,000 cycles. As a person grows

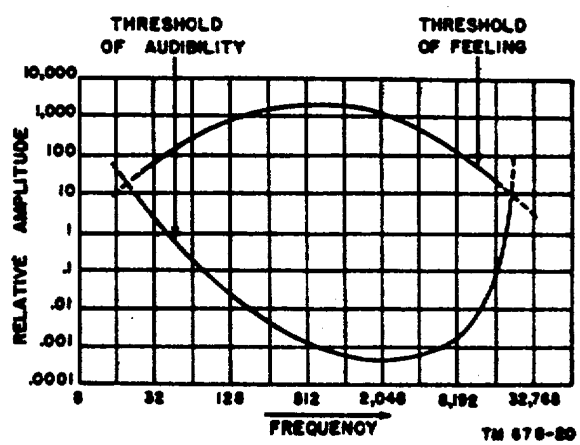

Figure 9. Curves of normal hearing ability.

older, the ability to hear sounds of higher frequencies gradually diminishes.

c. As the amplitude of a sound wave is increased, the sound becomes louder, until a point is reached where the sound is no longer heard. The body continues to feel the vibrations, however. If the amplitude is increased still further, a point is reached where there is a sensation of pain. This point is called the *threshold of feeling*, and it, also, varies with frequency and with the individual. The upper curve of figure 9 shows the threshold of feeling of the average person, and how it varies with frequency.

14. Face-to-Face Conversation

A statement of the larger factors involved in face-to-face conversation will prove of value in helping the reader to grasp the more complex problems encountered in the transmission of sound over telephone wires. In face-to-face conversation, the speech sounds of one person are transmitted to the ears of another by means of the intervening air. The distance between the individuals usually is small, so that there is very little loss (attenuation) of power in the transmission process, and the speakers may keep their voices at a normal conversational level. One is accustomed to the way the voice of an acquaintance sounds during face-to-face conversation, and hears in the voice what he feels is complete *naturalness* of tone and quality. (He even hears in his own voice what he thinks is complete naturalness of tone and quality, although surprised at the differences revealed by a voice recording.) Also, in face-to-face conversation, additional meanings are received from the facial expressions and gestures which accompany the spoken words. This is an important factor, especially for the many people who are hard of hearing, for it aids in comprehension of the ideas being transmitted. It also helps any listener to concentrate on conversations taking place amid sources of distraction, such as other conversations and unusual noise.

15. Conversation by Telephone

The relatively low power of speech sounds limits the maximum distance over which individuals may conduct face-to-face conversation. An attempt to converse at greater distances usually results in a lower degree of intelligibility. For communication over greater distances, some other means of transmitting the voice is required, and the telephone is the simplest device for this purpose. However, although the telephone succeeds in performing this primary function, its operation presents some rather complex problems which do not occur in transmission of sound through air. These problems include distortion of the sound, noise generated mechanically and electrically in the telephone system, noise from external sources, the cutting off of some of the low- and high-frequency components of the sound, and the reduction in volume (attenuation) which occurs in long-distance transmission. All of these problems tend to reduce the intelligibility of the words, the naturalness of the tone, and quality of the sound. They arise from the wires, from the component parts of the equipment, and from the associated circuits required for the generation of power. The engineer must take account of these problems in designing telephone equipment, and both the operator and the maintenance man must be familiar with them to secure the best possible operation of the equipment. Particularly, distortion of sound and distraction from external sources must be kept at a minimum, since personal contact, so important in face-to-face conversation, is lacking.

16. Summary

a. Sound waves are caused by the vibration of a rigid or semirigid body.

b. The transmission of sound always requires a medium; the transmission of light or electromagnetic waves does not require a medium. Air is usually the medium for sound transmission, but either liquid or solid mediums can be used.

c. Vibrating bodies set up alternate condensations and rarefactions in adjacent groups of air particles. These particles transfer their motion in turn to the next group, and this continuing action produces a wave of energy.

d. A cycle is a complete set of pressure values, from one positive peak to the next, anywhere along the path of the wave. The maximum pressure value, measured from the zero axis, is called the amplitude of the wave.

e. Wavelength is the actual distance between successive condensations or successive rarefactions along the path of the sound.

f. The time required for 1 cycle is called the period of the wave.

g. Frequency is the number of cycles per second.

h. The velocity of a sound wave is the distance the energy travels in a unit of time, usually expressed as feet per second. The velocity of sound in air is 1,090 feet per second at 0° C. and 1,130 feet per second at 20° C. By comparison, light and electromagnetic waves travel at a velocity of 186,000 miles per second.

i. The wavelength of a sound wave can be calculated by the following relationship:

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}}$$

j. The frequency range of audible sound is approximately 20 to 20,000 cycles per second.

k. In air and at a velocity of 1,100 feet per second, the wavelength of the audible frequencies ranges from 55 feet to approximately two-thirds of an inch.

l. Sound waves may be simple or complex. A simple sound wave is a wave made up of a single frequency varying sinusoidally. A complex sound wave is one made up of more than one frequency.

m. The lowest frequency present in a complex waveform is called the fundamental frequency. Whole-number multiples of the fundamental frequency of a sound wave are called harmonics or overtones. The fifth harmonic of a 1,000-cycle sound is 5,000 cycles.

n. Pitch is the relative frequency of a sound. Loudness or volume is the relative amplitude of the wave producing a sound.

o. Quality or timbre is that charactertistic of a sound which makes it recognizable as a certain kind of sound. Quality depends on the number of harmonics present and on the relationship between the fundamental and its harmonics.

p. A musical tone is a complex but regular waveform rich in harmonics; noise is a complex but irregular waveform.

q. Human speech is characterized by its quality, inflection, and range. Inflection is the small variation in pitch or loudness which a speaker uses to place emphasis or special meaning on his words.

r. The sounds of the normal speaking voice are at fundamental frequencies between 100 and 300 cycles. The overtones contained in these sounds extend the voice range of frequencies to approximately 5,000 cycles.

s. The range of fundamental frequencies of the singing voice varies from about 80 cycles to 1,200 cycles; the overtones reach as high as 10,000 cycles.

t. The range of fundamental frequencies of a symphony orchestra varies from about 16 to 4,000 cycles, with overtones to 12,000 cycles or higher.

u. Most telephones are limited in frequency response to the range from 200 to 2,700 cycles.

v. Speech transmitted by telephone introduces some distortion, noise, and frequency limitation, causing loss in intelligibility, naturalness, and quality.

w. The average power contained in speech at a normal conversational level is about 10 microwatts; at the loudest level it is about 1,000 microwatts; at the weakest level it is about 1/10 of a microwatt; at a whisper it is about 1/1,000 of a microwatt.

x. For any given frequency, the threshold of audibility is the lowest intensity at which sound is audible, the threshold of feeling being the lowest intensity causing a sensation of pain.

17. Review Questions

a. How is sound produced?

b. How can it be demonstrated that a medium is necessary for the transmission of sound?

c. Explain how a vibrating body transmits its motion to the adjacent air particles.

d. Define (1) frequency, (2) wavelengths, (3) cycle, (4) period, (5) velocity, and (6) amplitude.

e. What is the velocity of sound in air at 0° C. and at 20° C.?

f. Give the formula for determination of wavelength by velocity and frequency.

g. Thunder is heard 10 seconds after a lightning flash is seen. If the temperature of the air is 20° C., how far away did the lightning strike?

h. What is the wavelength in air of a 2,500-cycle sound, if the velocity is 1,100 feet per second?

i. What are the differences between simple and complex waveforms?

j. What is the difference between the fundamental frequency of a sound wave and its harmonics and overtones?

k. What is the frequency of the first harmonic of a 400-cycle note? Of the fourth overtone of middle C?

l. Define (1) pitch, (2) loudness, and (3) quality.

m. How does noise differ from speech or musical sounds?

n. What is the range in frequency of a normal speaking voice? Of singing? Of a symphony orchestra?

o. What is inflection?

p. What is the approximate frequency range of the human ear?

q. What is the frequency range of a telephone?

r. What is the average power, approximately, in the sound of (1) the normal speaking voice, (2) a loud shout, and (3) a whisper?

s. Define (1) the threshold of audibility, and (2) the threshold of feeling.

t. What are some of the advantages of face-to-face conversation?

u. What factors must be overcome in the transmission of sound by telephone?

CHAPTER 2

TRANSMITTERS AND RECEIVERS

18. Introduction to Telephony

a. Historical Background of Telephone.

(1) The combination of principles on which the operation of the telephone is based was discovered in 1875 by Alexander Graham Bell. At once, Bell started a series of experiments to perfect practical instruments for the transmission of sound over wires. After 9 months, the first complete sentence was transmitted, over an indoor line extending a distance of about 150 feet. By 1877, an outdoor line from Boston to Cambridge, a distance of about 2 miles, was in use. The early instruments were crude and not too effective. They operated on the principle that a diaphragm, vibrating in a magnetic field, can induce an electric current in a wire. The same device was used as both transmitter and receiver. The strongest magnets and best diaphragms then available would not permit transmission over long distances.

(2) One year after the invention of the original telephone, however, the perfection of the Blake transmitter made possible good, practical telephone transmission. This transmitter operates on the principle that the vibration of a diaphragm can vary the strength of an already existing electric current. Immediately, the problem was presented of establishing a means to connect the lines of different subscribers, whenever they wished to talk. This problem was overcome in 1878 with the opening of the first central office, or exchange, in New Haven. By 1900, means were evolved for the telephone user and exchange to signal (ring) each other when calls were to be initiated or completed. Present-day telephone systems provide vast improvements over those of earlier design and construction in the distances over which satisfactory transmission can be accomplished, dependability of established plant facilities, and the quality of the reproduced signals.

b. Basic Functions of Telephone System.

(1) By means of the telephone, conversations may be held over great distances. To accomplish this, the sound waves of speech must be converted into a form of energy that can be transmitted efficiently over wires. The conversion is effected by *electrical waves* (current) in the *transmitter* of the speaker's telephone set. There, electrical waves are created which correspond to sound waves both in waveform and frequency. The electrical waves are transmitted over the wire, or *transmission* line, and enter the *receiver* of the listener's telephone set. The receiver converts the electrical waves back into sound waves which, again, correspond in waveform and frequency to the original sound waves. The listener in his receiver thus hears words corresponding to those spoken into the distant transmitter.

(2) This process is shown in block form in figure 10. Above, on each side, is a graph of the sound waves as spoken and heard. The electrical wave is shown in the center.

(3) The fundamental principle of the telephone can be summarized by the explanation that electrical waves, traveling over wires, are substituted for sound waves, traveling in air, over the major portion of the distance separating the speaker and listener. Various types of telephone systems are in use, but this underlying principle is common to them all.

19. Telephone Transmitter

a. Function of Telephone Transmitter. The function of the *telephone transmitter* is to convert waves of sound into waves of electric current of corresponding waveform and frequency. The

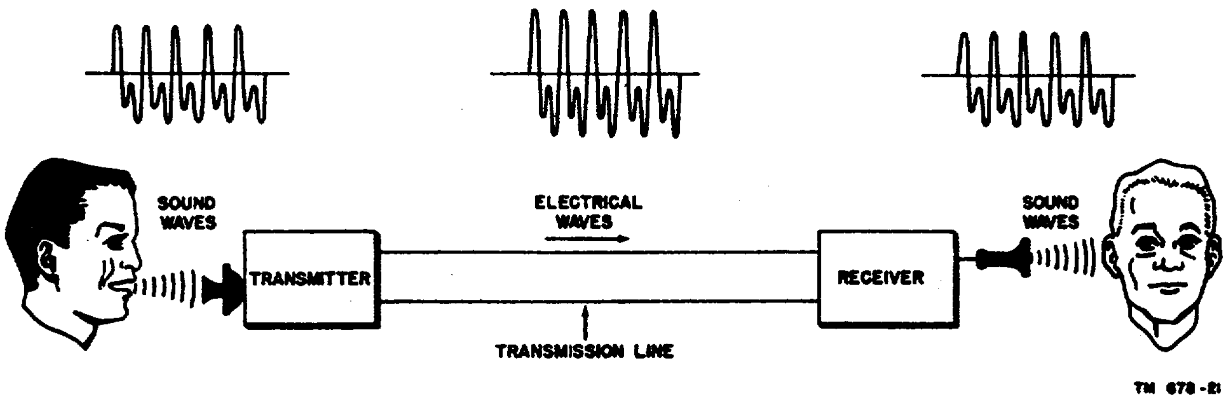

Figure 10. Transmission of sound by telephone.

energy of the waves of electric current so generated must travel over wires for relatively long distances, and arrive at the receiver at a level providing normal listening. But energy is lost in transmission over wires. Because of this loss, the initial energy of the electrical waves must be made *greater* than the original energy of the sound waves. The circuit of the transmitter therefore must provide a means of supplying this extra energy to the electric waves which it generates.

b. Telephone Transmitters.

(1) Paragraph 18*a*(1) describes the principle of operation of the earliest type of instrument used as a transmitter. This type of transmitter had a coiled wire wound around one pole of a permanent magnet, and a thin metal wafer of magnetic material, called the diaphragm, mounted adjacent and at right angles to the magnet. Sound waves colliding with the diaphragm would cause it to vibrate at a frequency determined by the frequency of the condensations and rarefactions of the air molecules, as illustrated in figure 4. It will be understood that the intensity of these condensations and rarefactions vary with each change in characteristic among the various sound waves, and that the amplitude of each diaphragm motion also will be affected by the same conditions; accordingly, the frequency and the amplitude of the diaphragm vibrations will cause the density of the magnetic field, in which it is located, to change with each change of position of the diaphragm. Since this varying magnetic field is cutting across the coiled wire, a voltage is induced in the wire. The voltage thus induced is alternating, since all induced voltages are alternating voltages.

(2) If two wires now are connected to the coiled wire ends and their extremities are connected in turn to another instrument similar in construction to that described in (1) above, the induced a-c voltage will cause a variation in the strength of the associated permanent magnet, and, since the strength of the permanent magnet field determines the instantaneous position of the diaphragm, each change in current intensity and direction of flow will cause a change in the position of the diaphragm. Because these changes are at the same frequency as those of the diaphragm at the originating point, the diaphragm at the terminating point will reproduce the same waves established originally.

(3) This entire process encompasses the changing of sound energy into electric energy, transmitting the signals electrically and then reconverting the electric energy into sound energy.

(4) The distance of which this process can be applied usefully is quite limited, since no provisions are made for amplifying the original energy provided by the sound waves present at the originating end. If all of this energy could be reserved for operating the diaphragm at the distant end, the distance between telephones could be extended almost indefinitely; however, this cannot be so, because part of the original energy is used in overcoming the inertia of the adjacent dia-

phragm; there are, also, further energy losses in the connecting wire, in the coils at both ends of the connections, in the two permanent magnets, and again in overcoming the inertia of the diaphragm at the distant end. The useful energy then is that which appears as sound at the distant end and it can be only the original energy minus all the energy losses.

(5) The only source of power furnished the instruments discussed above is that supplied by the person speaking, assuming speech transmission. Such transmission thus is said to be accomplished by use of a sound-powered transmitter, which is discussed further in chapter 8. As a matter of interest, such a transmitter actually is used in present-day communications as a receiver. As explained in paragraph 12, the average power contained in speech at a normal conversational level is about 10 microwatts. It is this power limitation, plus the lack of amplifying facilities, that limits the distances over which such instrumentalities can provide satisfactory sound transmission.

(6) The transmission limitations of the sound-powered transmitter were overcome with the advent of the carbon transmitter, the operating principles of which are described below.

20. Carbon Transmitter

a. Operating Principle of Carbon Transmitter.

(1) The *operating principle* of the *carbon transmitter* can be explained with the help of the simplified circuit shown in figure 11. The circuit consists of battery B and variable resistance R which represents the variable resistance of the carbon granules. Assume that the battery has an emf (electromotive force) of 6 volts, and that R may be varied from 0 to 1000 ohms, with a normal setting of 300 ohms. The normal or average value of current I that flows is 6 volts divided by 300 ohms, or 20 ma (milliamperes). If the resistance, R, is reduced to 240 ohms, the current increases to 25 ma, and if the resistance is reduced further to 200 ohms, the current increases to 30 ma. Similarly, if R is increased to 400 ohms, the current decreases to 15 ma, and if R is increased further to 600 ohms, the current decreases to 10 ma. If the resistance is varied continuously about its normal value of 300 ohms in a certain manner, the variations of current about its average value of 20 ma can be tabulated as follows:

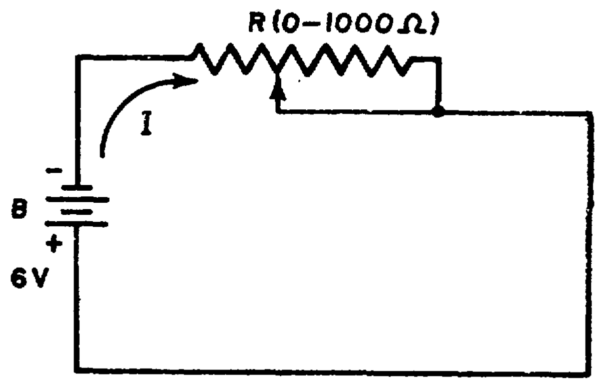

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Figure 11. Equivalent circuit of carbon transmitter.

Time (milliseconds)	Resistance (ohms)	Current (milliamperes)
0	300	20.0
1/3	240	25.0
2/3	209	28.7
1	200	30.0
1 1/3	209	28.7
1 2/3	240	25.0
2	300	20.0
2 1/3	400	15.0
2 2/3	531	11.3
3	600	10.0
3 1/3	531	11.3
3 2/3	400	15.0
4	300	20.0

(2) Figure 12 shows the graph of current versus time constructed from this tabulation. The current waveshape is one of pulsating direct current. This consists of an a-c (alternating-current) wave superimposed on a d-c (direct-current) or average, value of current. The [illegible] component is 20 ma, and the a-c component is a sine wave with an amplitude of

10 ma. The period of the wave, or the time for 1 cycle, is 4 milliseconds, or .004 second. The frequency of the wave can be calculated by using the formula:

$$f=\frac{1}{\text{period}}$$

$$f=\frac{1}{.004}=250 \text{ cycles.}$$

The rate at which the current varies about its average value depends on the rate at which the resistance is varied about its normal value.

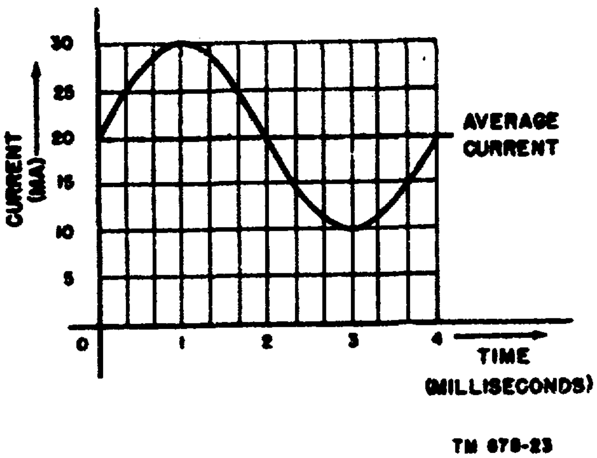
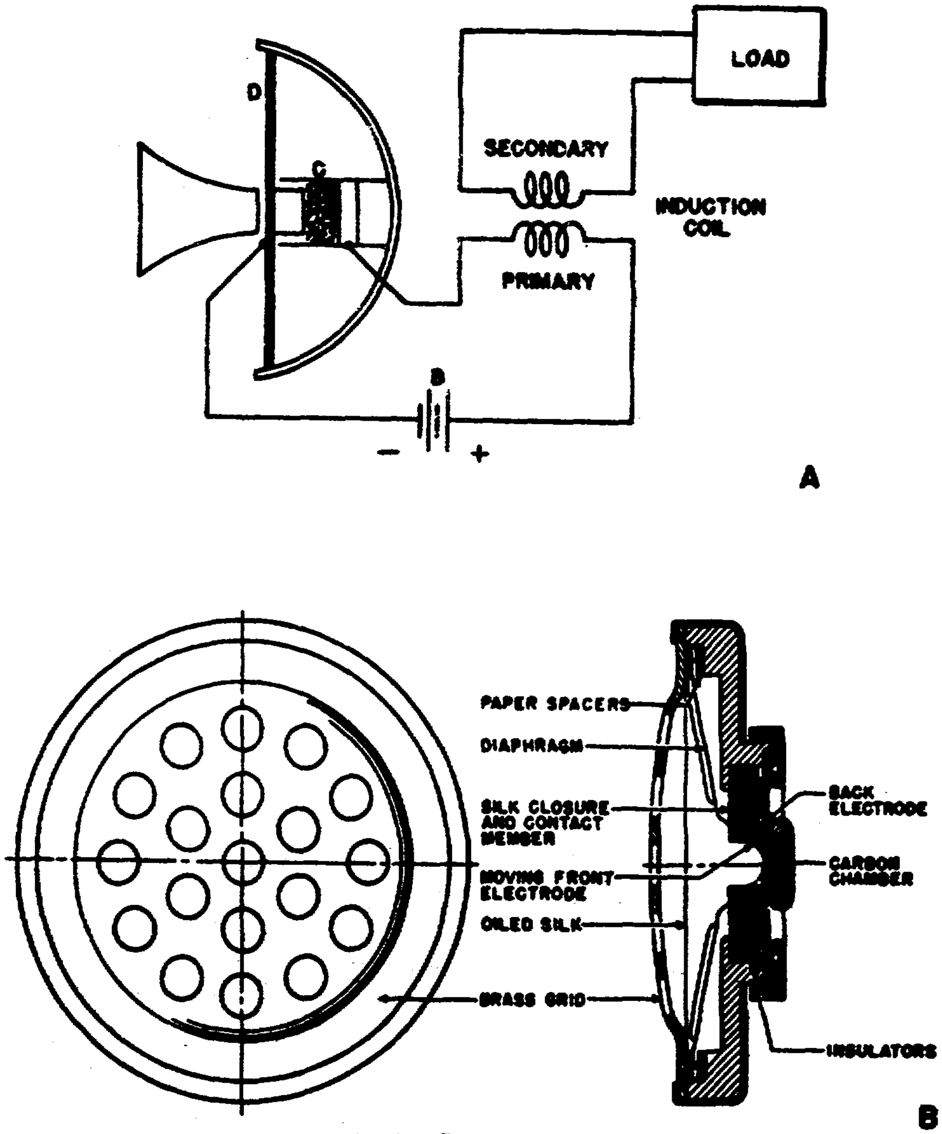


Figure 12. Current versus time.

b. Application of Operating Principle To Carbon Transmitter. A, figure 13, illustrates the operation of the carbon transmitter, the principle of which is based on the simplified circuit in figure 11. The basic circuit components are battery, B, a cup of carbon granules, C, metal diaphragm, D, and an induction coil. The negative terminal of the battery is connected to a small carbon disk which is fastened rigidly to the diaphragm. This disk rests against one side of the cup of carbon granules; the other side of the cup is connected to one end of the primary of the induction coil. The circuit is completed by the return of the primary to the positive terminal of the battery.

(1) When no sound waves strike the diaphragm it remains stationary, the resistance of the carbon granules remains constant, and, as a result, a steady direct current flows through the circuit (A, fig. 13). The value of this current depends on the combined resistance of the carbon granules and the d-c resistance of the primary of the induction coil. Since an induction coil is, in effect, a transformer, no emf is induced in the secondary when steady direct current flows in the primary. Therefore, when no sound energy is transferred to the diaphragm (that is, when the diaphragm does not move), no current flows in the secondary of the induction coil. The normal resistance of an actual new transmitter unit is approximately 35 ohms; the d-c resistance of the primary of the induction coil varies with the type of coil used. These coils will be discussed more completely in a later chapter.

(2) When sound waves strike the diaphragm, it vibrates in accordance with the variations of intensity and frequency of the waves (A, fig. 13). This vibration causes a varying pressure to be exerted on the carbon granules, which changes their state of compression. As the compression increases, the resistance of the granules decreases, causing the current in the circuit to increase. As the compression decreases, the resistance of the granules increases, causing the current to decrease. Because the amplitude and frequency of the current vary directly as the amount and rate of change of the compression of the carbon granules, they vary as the amount and rate of change of the pressure exerted on the diaphragm, and, therefore, vary as the intensity and frequency of the sound waves which strike the diaphragm. The varying current is a pulsating direct current. (Figure 12 shows such a current, resulting from a simple wave. The a-c component of a current resulting from speech is, of course, a complex wave, but again it is superimposed on a direct current to form a pulsating direct current.) Because the emf induced in the secondary (A, fig. 13) depends only on the varying component of the current in the primary, an alternating emf is induced in the secondary. When a load, such as a meter or receiver, is connected to the secondary, an alternating current flows in the secondary circuit.



A. Circuit. B. Structure. TM 678-1515

Figure 13. Carbon transmitters.

21. Structure of Carbon Transmitter

a. B, figure 13, shows the front view and a cross-sectional side view of a carbon transmitter. This unit is one of several types in common use, all with a similar basic structure. The path of current within the unit is from the moving front electrode, which is fastened to the diaphragm, through the carbon granules, to the back electrode. A bell-shaped carbon chamber is used, so that there is sufficient contact between the carbon granules and the electrodes. Since the contact is uniform, and operation is equally good in whatever position the transmitter is held, this is called a *nonpositional transmitter.* The moving front electrode exerts varying pressure on the granules in accordance with the vibration of the diaphragm, and the transmitter consequently is of *direct-action type.* As the diagram shows, the moving electrode is attached to the center of the conical diaphragm, and forms the front center surface of the carbon chamber.

b. The diaphragm is made of an aluminum alloy (B, fig. 13). Its thickness is .003 inch, and it has radial ridges to increase its stiffness. Paper spacers, consisting of a number of thin paper rings, support the diaphragm at its edge without interfering with its movement. The carbon cham-

ber is closed on the front side by a silk covering, clamped on the flange of the front electrode. A light, spoked, copper contact member, clamped under the front electrode, provides a flexible connection between the front electrode and the metal frame. The stationary back electrode is held in place in the frame by a threaded ring, and is insulated from the frame by a fiber washer and a ceramic insulator, which also forms part of the rear surface of the carbon chamber. The surfaces of both front and back electrodes are gold-plated where they make contact with the carbon granules. The perforated brass grid protects the vibrating parts from mechanical injury. The working parts are kept free of moisture by an oiled-silk membrane stretched between the brass grid and the diaphragm.

c. The transmitter unit is mounted in a handset, as shown in the disassembled view of figure 22. It is held in place by the transmitter cap, along with contact springs which press against its contact. The unit may be removed for servicing by unscrewing the plastic cap or mouthpiece.

d. An improved type of carbon transmitter is shown in figure 14. The frequency response of this unit has been improved by use of an acoustic network which couples the back chamber of the diaphragm through an acoustic resistance to the cup chamber. Woven rayon fabric is used for the acoustic resistance material. This transmitter, in addition to an improved frequency response, has a high modulation efficiency. Note that the diaphragm of this transmitter is clamped rigidly at its outer edge, whereas the diaphragm of the element in B, figure 13, is floated between paper spacers.

22. Noise-Canceling Transmitter

a. The transmitter shown in B, figure 13, has a major disadvantage in that it is susceptible to in-

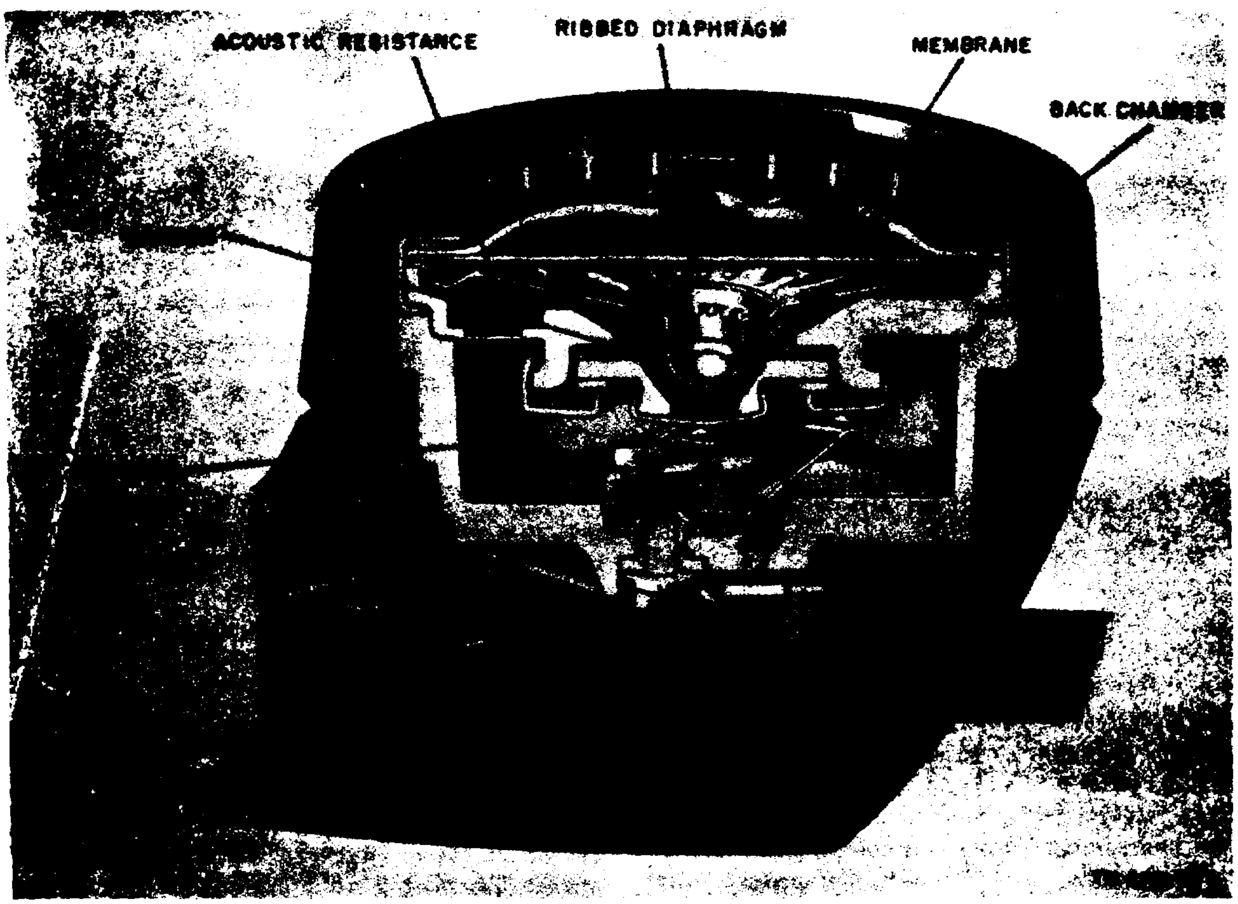


Figure 14. Modern transmitter.

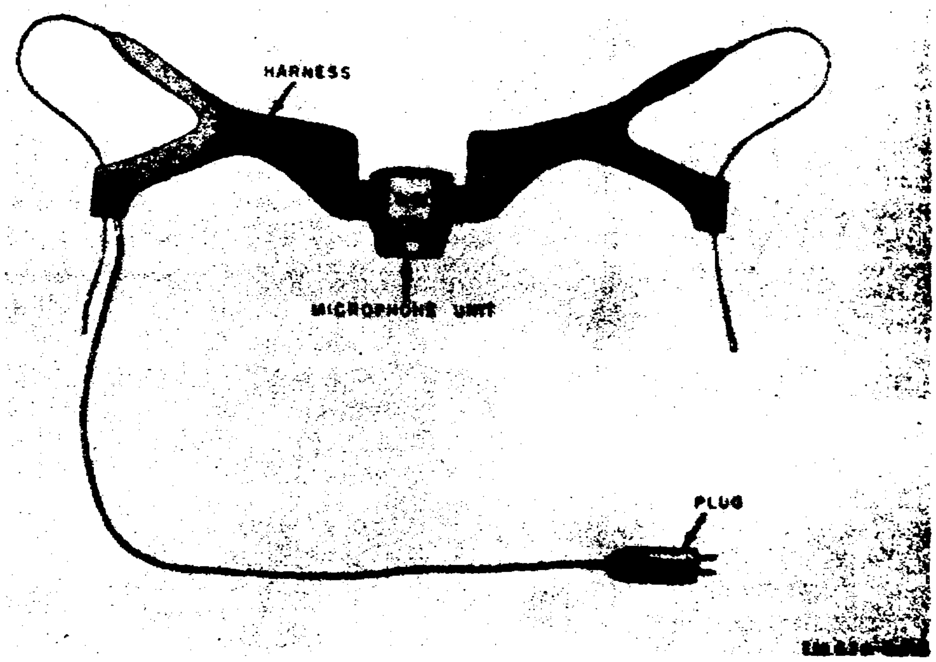


Figure 15. Differential transmitter.

terference from noise. This disadvantage is most noticeable when the transmitter is operated in places where the noise level is high, such as near railroad trains, airfields, the interior of tanks, and areas where gunfire or bombardment is taking place.

b. A number of transmitters have been developed which reduce interference from noise sources. Among these are the throat transmitter and various kinds of directional transmitters, which restrict the movements of the operator and produce some distortion of his speech. Recently, however, a transmitter has been developed which largely eliminates noise interference without restricting movement. It is called a *noise-canceling* or *differential* transmitter.

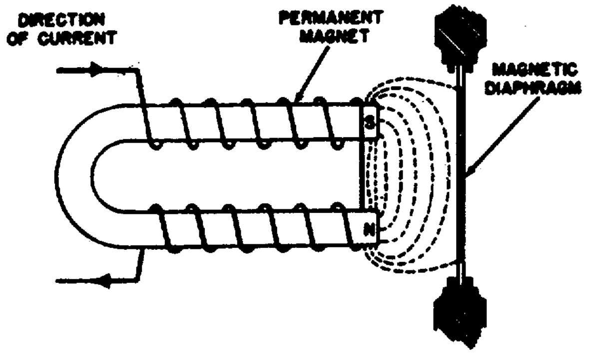
c. The United States Army Type T-45 lip transmitter is an example of this type. In operation, sound waves activate its diaphragm only if they are introduced close and perpendicular to the front surface of the diaphragm. Sounds which originate at some distance enter the transmitter through two openings, on the front and back of the diaphragm. Since this equalizes the pressure exerted on both faces, the resultant motion of the diaphragm for distant sounds is practically zero. There is almost no change in the resistance of the carbon granules and, therefore, almost no change in current as a result of these sounds. Since, in responding to distant sounds, the diaphragm neutralizes pressures of relatively low frequencies more than those of high frequencies, the noises most canceled are those originating in tanks and from gunfire, mainly in the low-frequency range. By proper design, it is possible to make the cancellation of noise practically complete. This feature makes the differential transmitter much more suitable than others for many military applications, and also makes it valuable for many civilian uses.

23. Telephone Receivers

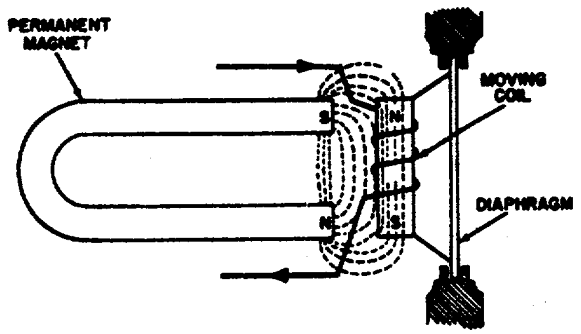
a. Function of Telephone Receiver. The function of the *telephone receiver* is to reproduce the sound made in the transmitter at the other end of the transmission line. It is accomplished by reconverting to sound waves the electrical waves transmitted to it. The function of the receiver, therefore, is the reverse of that of the transmitter. The receiver also must prevent leakage of sound. This requirement is satisfied by the construction of the earpiece, which is designed to be held close to the ear.

b. Types of Telephone Receivers. According to their means for converting electrical waves to sound waves, telephone receivers may be either magnetic-diaphragm or moving-conductor types.

(1) The *magnetic-diaphragm receiver* (A, fig. 16) contains a permanent magnet, and operates by variation of the strength



MAGNETIC-DIAPHRAGM RECEIVER A



MOVING-COIL RECEIVER B

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Figure 16. Comparison of operating principles of two receivers.

of its magnetic field. The amplitude and frequency of the variation of the magnetic field cause a corresponding variation of the motion of the magnetic diaphragm. This is the receiver most commonly used in telephone communications.

(2) The *moving-conductor receiver*, shown in B, also contains a permanent magnet, but it operates on the principle of the electrical meter. The moving conductor is usually a coil or ribbon of aluminum alloy, attached to the diaphragm. As the current in the coil varies, the magnetic field around the coil varies. This varying field reacts with the field of the permanent magnet, causing the coil to vibrate. The vibrations of the coil are transferred to the diaphragm, which generates sound waves of the same frequency and waveform characteristics as the current in the coil. The moving-conductor receiver is called also the *moving-coil receiver* and the *dynamic receiver*. The dynamic loudspeaker used in radio receivers is similar to it in action.

24. Magnetic-Diaphragm Receiver

a. *Operating Principle of Magnetic-Diaphragm Receiver.* The *operating principle* of the *magnetic-diaphragm receiver* (fig. 17) is based on an elementary principle of magnetism—the ability of a magnet to induce a magnetic field of opposite polarity in a magnetic material placed near it. Because the induced polarity is opposite, attraction always results between the magnet and the material. For example, a magnet and an iron nail are attracted to each other.

(1) When a magnetic diaphragm is placed near the bar magnet, as in A, and its range of motion is limited suitably, it will be attracted to the magnet without actually touching it. The magnet exerts a permanent pull on the diaphragm. If a coil is wound around the magnet as in B, C, and D, and current is caused to flow in the coil, the pull on the diaphragm will be increased or decreased, depending on the direction and magnitude of the current. If the current in the coil is a sine-wave alternating current, it varies the strength of the magnetic field accordingly. During the positive half-cycle of such current, shown in B, as the current varies from 0 to maximum and back to 0, the strength of the magnetic field varies from its original value to *maximum* and back to its original value. The pull on the diaphragm at the same time varies from its normal value to maximum and back to its normal value. During the negative half-cycle in C, as the current varies from 0 to maximum in the opposite direction and back to 0, the strength of the magnetic field varies from its original value to *minimum* (because of the reversed direction of current) and back to its original value. The pull on the diaphragm at the same time varies from its normal value to minimum and back to its normal value. These actions in sequence cause a vibration of the diaphragm. The vibration is actually a

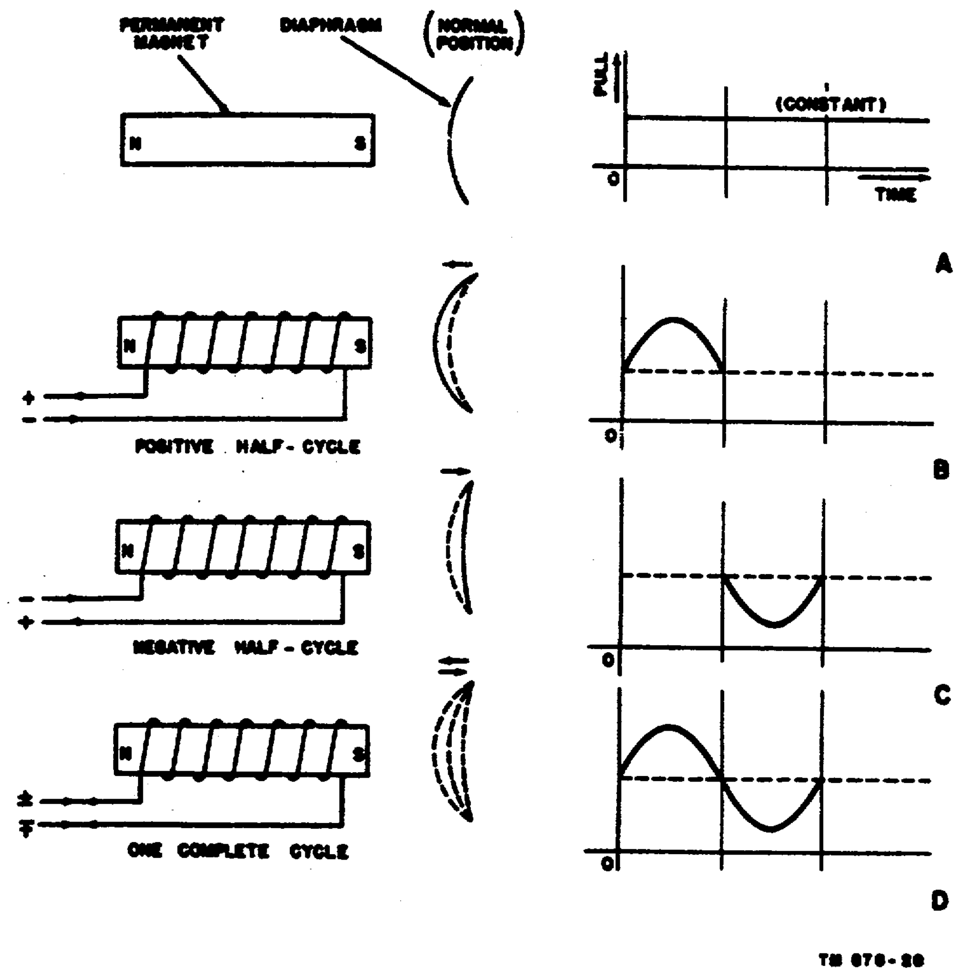


Figure 17. Operation of magnetic-diaphragm receiver.

sinusodial displacement of the diaphragm about a normal, or neutral, position, shown in D. A series of vibrations results in the generation of a series of sound waves of corresponding frequency and waveform. Figure 18 shows comparative graphs of the sound-wave input at the transmitter, the current in the transmitter, the magnetic pull on the diaphragm, and the sound-wave output at the receiver.

(2) Figure 19 illustrates the reason for using a permanent magnet in the telephone receiver. The permanent magnet is replaced by an electromagnet, with a coil wound on a soft-iron core. When no current flows in the coil, there is no magnetic field; therefore the diaphragm remains in its neutral position, as in A. When a sinusodial current flows in the coil during the positive half-cycle, a magnetic field of similar variations is produced, as in B, and this field attracts the diaphragm so that its motion corresponds to the variation of the field. During the negative half-cycle, in C, the polarity of the magnetic field is reversed, but the displacement of the diaphragm is exactly as before, since only attraction (not repulsion) can be exerted on it; consequently, the diaphragm moves inward for *both* half-cycles of current, instead of alternately inward and outward as described in (1) above. The sound wave produced by this action would have *two* condensations and *two* rarefactions for each cycle of current. The sound, therefore, would have a fundamental frequency twice as great as that of the current, as well as a distorted waveform.

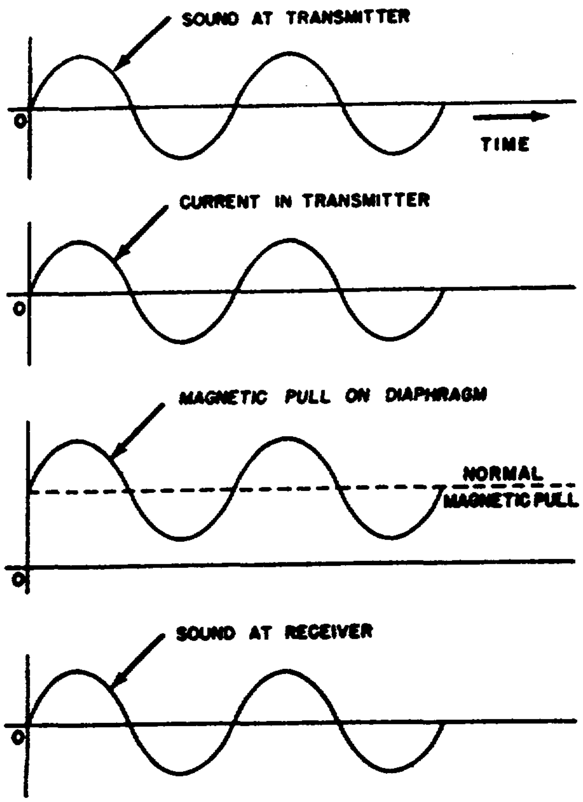


Figure 18. Waveforms in simple telephone system.

Since these results would cause the sound to be considerably different from the original sound introduced at the transmitter, this system, which does not contain a permanent magnet, would be useless for telephone transmission.

b. Application of Operating Principle To Practical Magnetic-Diaphragm Receiver.

(1) In the early telephone receivers devised by Bell, a bar magnet was used to supply the permanent magnetic field (A, fig. 20). Bell actually used two receivers of this type in his early telephone system, one serving as the transmitter and the other as the receiver. Later, the efficiency of the receiver was improved greatly by using a *horseshoe magnet* in place of the bar magnet, as shown in B. Because the length of the magnetic path is much shorter in the horseshoe magnet, the magnetic field is concentrated in the region between the poles. This increases the pull on the diaphragm for a given value of current, and therefore produces sound waves of greater intensity. The modern receiver unit incorporates a modification of the horseshoe magnet. This, with the use of better magnetic alloys, has improved the design and performance of the receiver.

(2) In a later chapter it will be shown that the receiver winding occasionally must have direct current flowing through it. Because of this requirement, the receiver is connected in such a manner that the field produced by the direct current in the coil aids the field of the permanent magnet. This increases the strength of the field, and results in a stronger pull on the diaphragm. The process by which direct current in the winding produces an aiding field is called *poling*, because the polarity of the direct current must be correct.

(3) Permanent magnets operate uniformly if they are not subjected to shocks or other abuse. Sudden and violent jarring partially destroys their magnetism, and makes them less effective in telephone receivers. A weak magnet exerts a weaker normal pull on the diaphragm, causing unequal displacement on each side. This results in distorted vibration and distorted sound.

25. Structure of Modern Receiver

a. C, figure 20, shows the front view and a cross-sectional side view of a *modern receiver unit*, designed to be mounted in several types of telephone instruments. The receiver winding is wound around two permalloy pole pieces, each of which is welded to a cobalt-steel bar magnet. These magnets are made of a recently developed magnetic alloy which has high permeability, giving a strong magnetic field. The magnets and pole pieces are fastened to a zinc-alloy frame. The diaphragm is made of a special steel alloy. It is not clamped, but rests on a ring-shaped ridge; the pull of the magnets holds it in place. It is protected in front by a silk screen, and its vibration is controlled by a silk acoustic resistance disk attached at the rear. The entire unit is held together by a brass clamping ring. Two silver-plated contacts, for electrical connections, are mounted on the back.

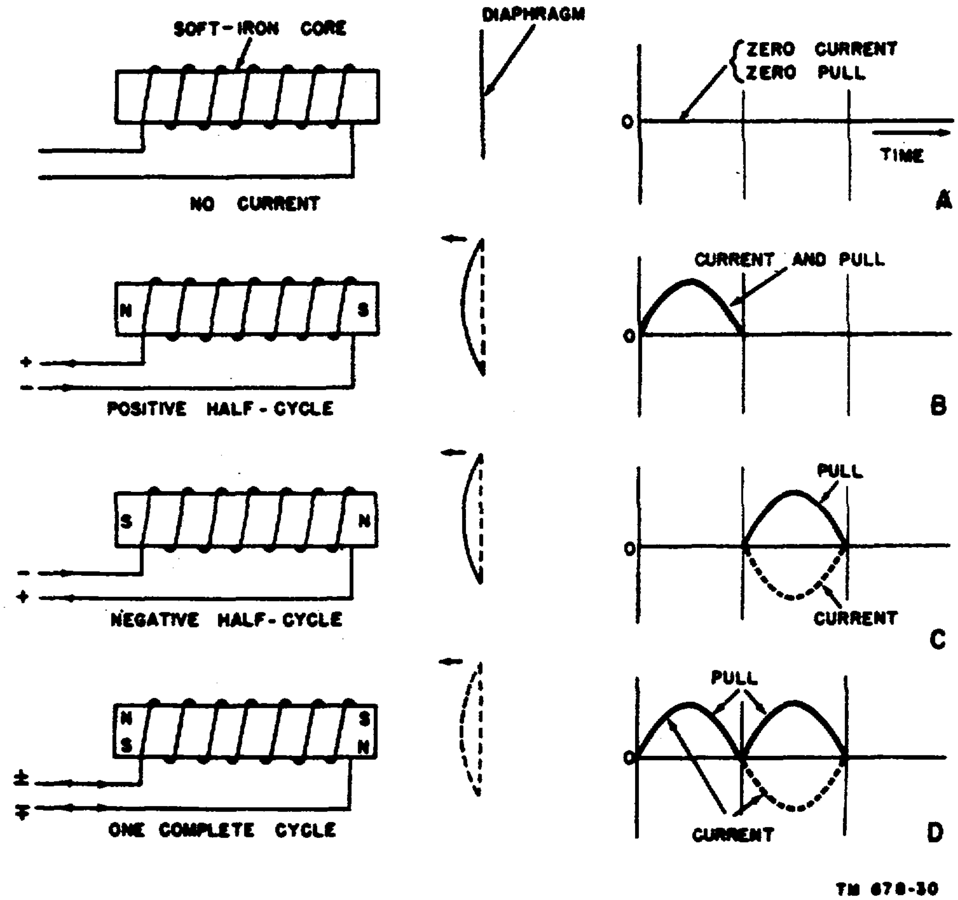


Figure. 19. Action of soft iron-ore electromagnet on diaphragm.

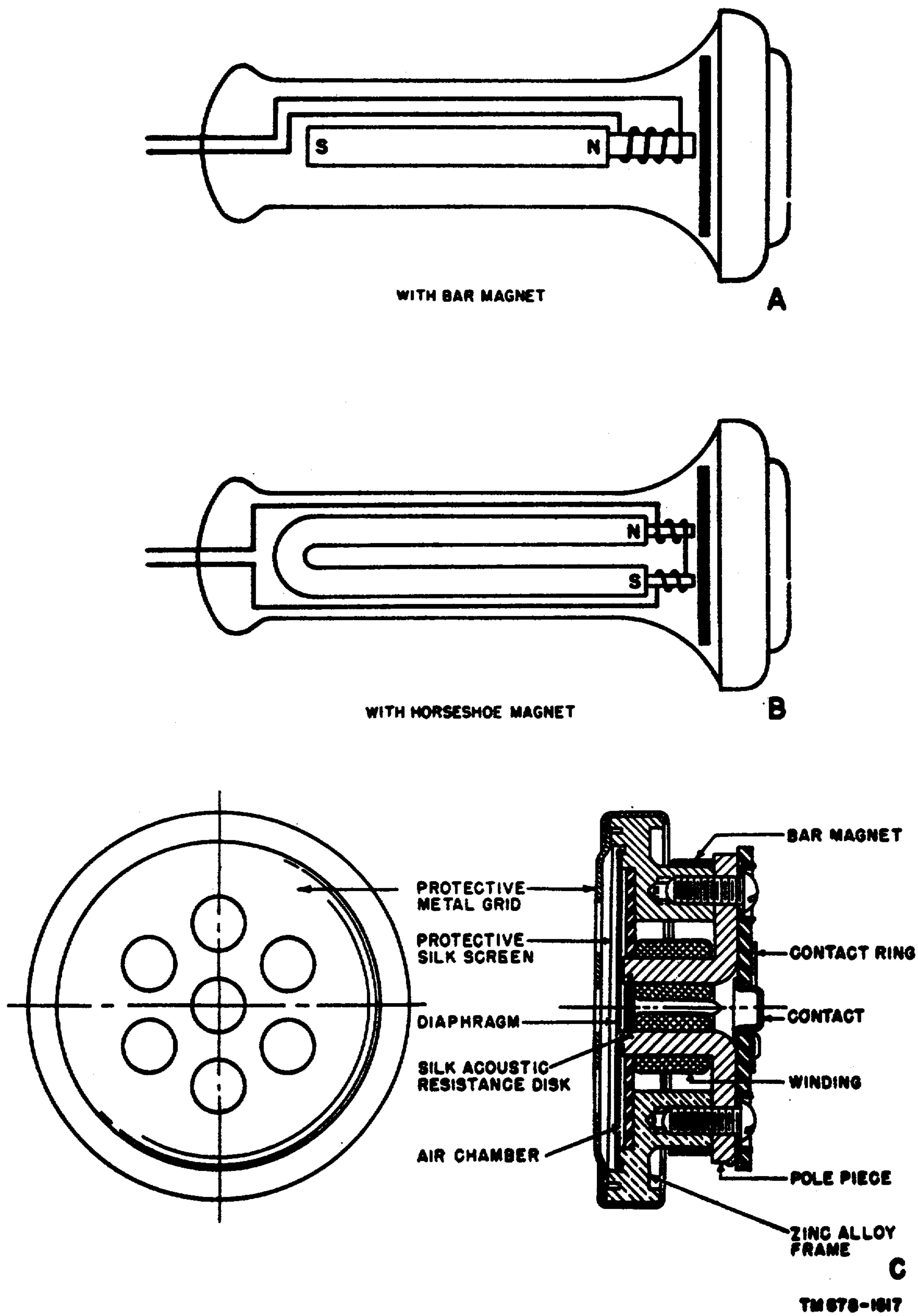
b. A recently developed receiver that provides improvements in efficiency and frequency response is shown in figure 21.

(1) The simple diaphragm of earlier receivers is replaced by a ring armature, a dome-shaped diaphragm of phenolic impregnated fabric cemented to a circular magnetic ring. The outer edge of the ring rests on a circular seat of nonmagnetic material. The inner edge is close to a circular pole piece which conducts the flux from a ring-shaped permanent magnet. This design lowers the mechanical impedance of the diaphragm and improves the radiation efficiency. As a result, when the receiver is held off the ear, the intelligibility of speech is much better than that of other receivers.

(2) An acoustical network couples the back chamber of the diaphragm through four holes covered with acoustic resistance fabric to the handset cavity. The chamber above the diaphragm exhausts through the holes in the receiver cap. The receiver response is virtually flat from 400 to 3,500 cps (cycles per second)—an improvement over earlier receivers.

(3) A varistor, or nonlinear resistance, protects the user from high acoustic levels caused by transient electrical disturbances in the telephone circuit. This varistor also protects the receiver magnet from demagnetization hazards of such disturbances.

c. The receiver and transmitter units are mounted for convenience in an instrument called a *handset.* Figure 22 is a disassembled view of a handset, showing the transmitter element, transmitter cap, receiver element, and receiver cap. When the receiver cap (earpiece) is screwed on tightly, it exerts a pressure on the receiver element, forcing the two contacts against two contact springs. These contact springs are connected



A and B, Early types. C, Modern unit.

Figure 20. Telephone receivers.

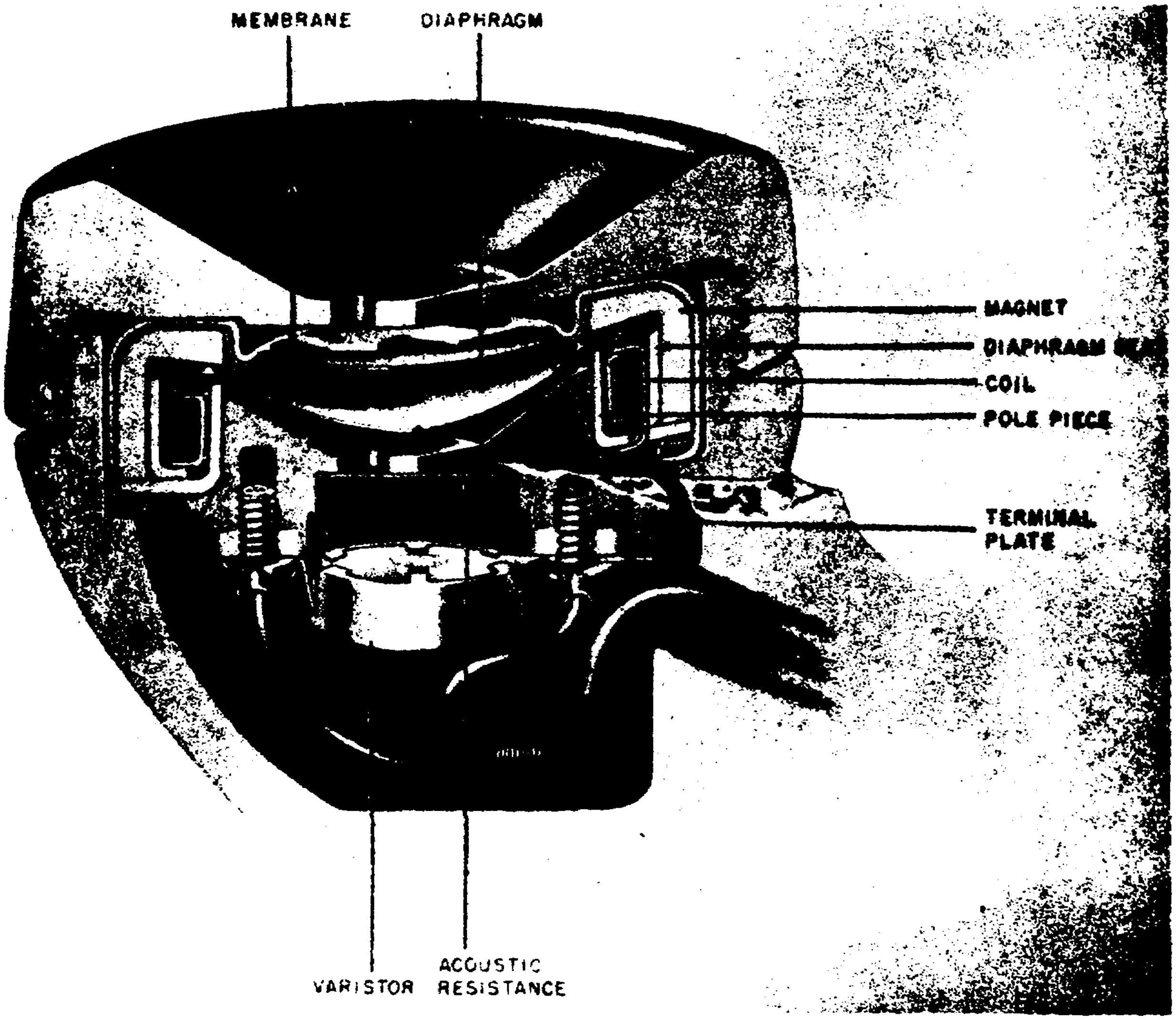


Figure 21. Modern receiver unit with ring armature.

to the external wiring of the receiver. Like the transmitter, the receiver element may be removed for servicing or replacement by unscrewing the cap. In the typical modern combined hand-telephone set shown in figure 23, the handset rests on a cradle base when not in use.

26. Circuit Diagrams

a. Identification of Components of Circuit Diagrams. The study of telephony involves an understanding of the operation and assembly of equipment consisting of many component parts. Some of the parts are small, some rather large. The process of learning is simplified greatly if these parts can be identified readily. Identification means more than recognizing them, however. It includes the ability to visualize how and where each part is connected in a circuit, and knowledge of the theory and function of the part in that circuit. It includes a thorough understanding of the relation of each part in a circuit to other parts, for only with this understanding can the skill necessary for tracing circuits be acquired. In later chapters of this manual which deal with actual telephone circuits, the theory and function of each part will be explained as soon as the part is introduced, and the relation of each part to the others in the circuit will be presented by means of text and diagrams.

b. Types of Circuit Diagrams (fig. 24). Three basic types of circuit diagrams—pictorial, wiring,

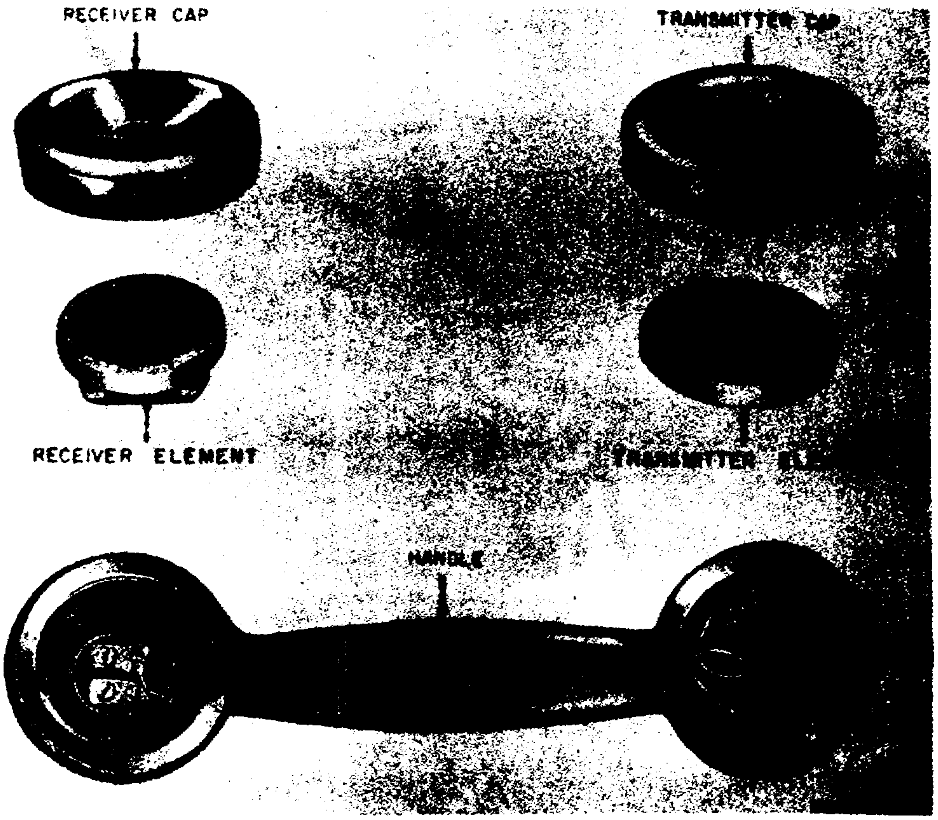


Figure 22. Handset, disassembled.

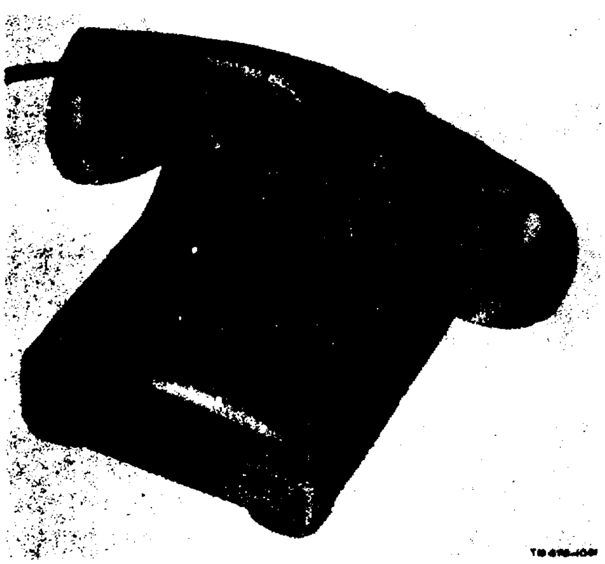


Figure 23. Modern combined hand-telephone set.

and schematic—will be used extensively in this manual, and now will be described. In addition, frequent use will be made of block diagrams.

(1) An example of a *pictorial diagram* is shown in A. This is a picture drawing of the actual physical layout or assembly of the component parts of a circuit, showing the parts either as they appear to the eye, or in a form which emphasizes some feature of their operation. The parts may be photographs of equipment, if they are arranged to show the relationships among them. Pictorial diagrams are useful particularly to people untrained in the theory of operation of the circuits they illustrate.

(2) B is an example of a *wiring diagram.* This type is used primarily to show a wireman or serviceman the proper hook-up for a piece of equipment. The emphasis in wiring diagrams is on the connection of cables and other wires to appropriate terminals, not on the operation of the circuit.

(3) The *schematic diagram*, shown in C, is not a lifelike drawing of the component parts of a circuit, or a means for indicating their connection. Instead, stand-

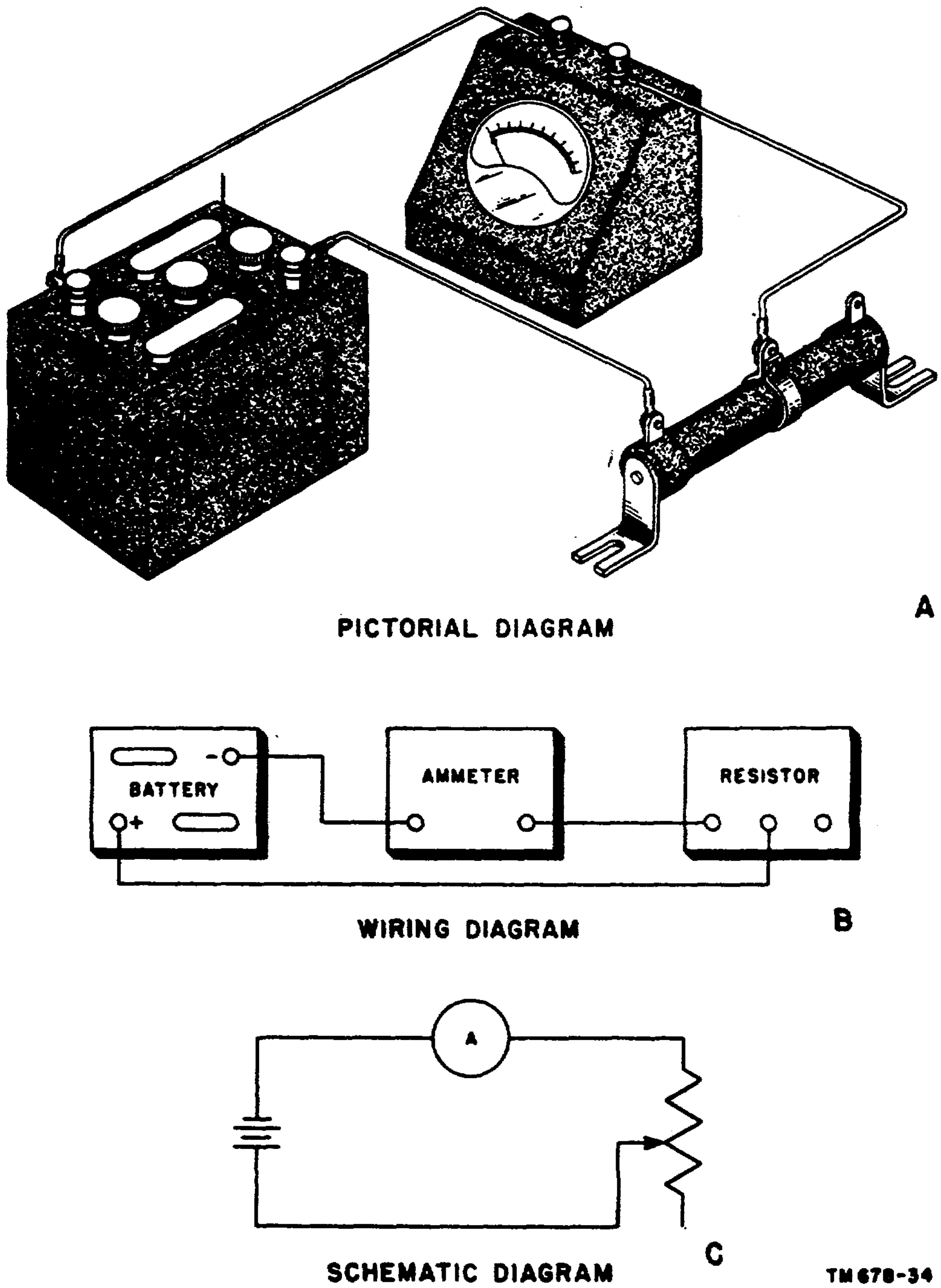


Figure 24. Types of circuit diagrams.

ard, conventional *symbols* are used, and the position of the symbols in the diagram does not necessarily correspond to the location of the parts in the actual equipment. Schematic diagrams usually are more compact and easier to trace than pictorial diagrams, and they are used more often. They make it possible to present a more logical explanation of the voltage and current relationships in electrical circuits than is possible with other types, and they allow the emphasizing of important features of the circuits. Schematic diagrams will be used extensively in explaining the operation of the telephone circuits discussed in this manual.

27. Reading of Schematic Diagrams

The ability to trace and understand the schematic diagrams of telephone circuits can be obtained rapidly if the problem is approached in an intelligent manner. Do not attempt to memorize complicated diagrams. The principles and procedures followed by telephone men, described below, should be followed to acquire skill in reading and understanding schematic diagrams.

a. Learn the *electrical principles* underlying the operation of the particular circuit. This includes a knowledge of the kinds of current flowing in the various parts of the circuit, the voltage across the various parts, and the power dissipated in the circuit.

b. Memorize the *symbols* for the component parts of telephone circuits. These symbols will be introduced at the time the operating principle of each part is explained. Learn to identify the symbol with the actual appearance of the part.

c. Break down a complex circuit into a number of simpler circuits. Frequently, certain small groups of parts form relatively simple units within a complex circuit. For example, a diagram of a complete telephone system can be broken down into a transmitter circuit, a receiver circuit, a ringing circuit, relay circuits, and several other smaller circuits. Learn to recognize these small groups as units, and to relate these units to the others. In the following pages, complete circuit diagrams will be built up step by step; and frequently, as each new smaller unit is introduced, its position in the circuit will be emphasized by the use of heavier lines than those in the rest of the circuit. Take advantage of this, not only to learn the function of the unit itself, but to understand its relation to the rest of the circuit.

d. Learn to think of each part or unit in a circuit in terms of its *function* in the circuit. An understanding of *why* a particular part is included is extremely helpful in learning its position in a schematic diagram. The reader actually will find himself looking for a particular part in a circuit diagram, if he understands its function.

e. Form the habit of visualizing the *position* of a unit in the actual equipment from its position in a schematic diagram of the equipment. This will prove helpful when it is necessary to work on the equipment from a schematic diagram. Remember that the position of the symbol in a schematic diagram does not correspond necessarily to the location of the unit in the equipment.

f. Learn to distinguish between the electrical circuit and the mechanical operations associated with the circuit.

g. Review, from time to time, the symbols learned previously, and the relationships among the smaller units which make up the complete circuit.

h. Follow faithfully all of the foregoing principles and procedures, for they are indispensable to the rapid acquiring of skill in the reading of schematic diagrams.

28. Telephone Symbols

This chapter has included discussions of the operating principles of telephone transmitters and receivers. These units, together with such electrical devices as batteries and resistors, are basic components of telephone systems. Figure 25 shows most of the *symbols* for the units and devices so far discussed. A more complete list of the fundamental electrical symbols used in telephone circuits is contained in the appendix.

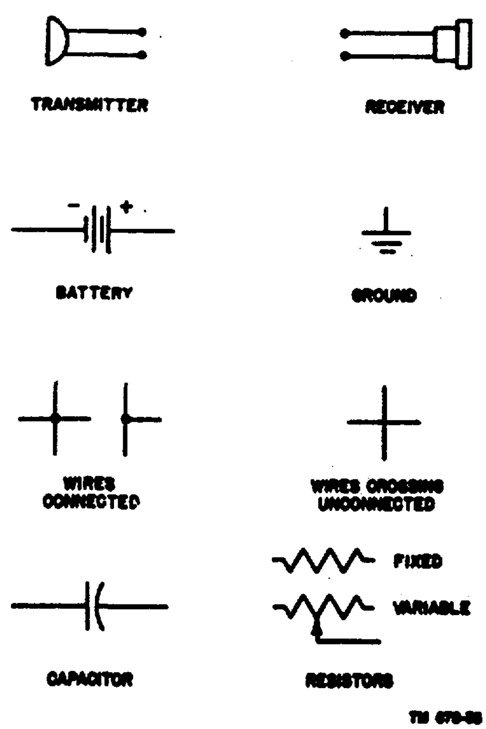


Figure 25. Telephone symbols.

29. Summary

a. The telephone as invented by Bell in 1875 was crude and limited in efficiency. Extending its area

of usefulness presented many problems. Within only a few years, many of its basic problems were solved.

b. Present-day telephone systems are very different from early ones, but they have the same basic principles of operation.

c. Sound waves, striking the diaphragm of a carbon transmitter, cause the diaphragm to vibrate with variations of frequency and amplitude corresponding to those of the waves. This causes a corresponding variation in the resistance of a chamber of carbon granules, which in turn causes a corresponding variation in the magnitude of a direct current produced by a battery. This pulsating direct current flows through the primary winding of an induction coil, and induces an *alternating* emf in the secondary winding. An alternating current flows through a load connected to the secondary.

d. Modern transmitters are designed, electrically and mechanically, for maximum efficiency and minimum distortion and interference from external noise.

e. The carbon transmitter is the most common of several types of transmitters in current use.

f. The electrical waves produced by the transmitter are sent over the transmission line and reconverted to sound waves in the receiver.

g. The magnetic-diaphragm receiver contains a permanent magnet which exerts a constant attraction on a diaphragm of magnetic material placed close to it. Around the magnet is a coil. The intensity of the magnetic field of the magnet in the receiver varies with the alternating current it receives from the transmission line running to the transmitter, and this causes an alternate increase and decrease in the pull exerted upon the diaphragm. The vibration thus set up produces sound waves which correspond in frequency and amplitude to both the electrical waves in the line and the originating sound waves at the transmitter.

h. Modern telephone receivers efficiently reduce interference from surrounding noise.

i. Skill in reading and understanding circuit diagrams, particularly schematic diagrams, is important in the study of telephony. Acquisition of skill is relatively easy if the proper procedure is followed.

30. Review Questions

a. Discuss, with the aid of a block diagram, the operation of the transmitter, transmission line, and receiver in a simple telephone system.

b. Describe the operation of the carbon transmitter.

c. State and explain the kind of current that flows in a carbon transmitter when the diaphragm is stationary; when the diaphragm is vibrating sinusoidally.

d. Describe the construction of a modern carbon transmitter with regard to its electrical operation; its mechanical strength and protection.

e. Describe the operation of the magnetic-diaphragm receiver.

f. Why is it necessary to use a permanent magnet with its associated coils rather than an electromagnet with an iron core and no permanent magnet in a magnetic-diaphragm receiver?

g. Why must care be taken to avoid sudden jarring of a telephone receiver?

h. Describe the features of construction of a modern telephone receiver which are concerned with mechanical protection.

i. Define poling, as applied to telephone receivers. Why is it necessary?

j. Explain the distinction between wiring and schematic diagrams.

k. Draw neat sketches of the conventional symbols for a battery; a transmitter; a receiver; a resistor; wires connected; wires crossing but not connected.